Noise and Morphogenesis
Uncertainty, Randomness and Control

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Abstract

This thesis presents a processual ontology of noise by virtue of which morphogenesis (in its most general understanding as the processes by which order/form is created) must be instantiated. Noise is here outlined as the far from equilibrium environment out of which metastable temporary 'solutions' can emerge as the system transitions through the pre-individual state space.

While frequently addressed by humanities and arts studies on the basis of its supposed disruptive character (often in terms of aesthetics), this thesis aims to thoroughly examine noise's conceptual potencies. To explore and *amplify* the epistemic consequences not merely of the ineliminability of noise but of its originative power as well as within the course of the elimination of givenness by epistemology.

This philosophical work is informed by many different fields of contemporary science (namely: statistical physics, information theory, probability theory, 4E cognition, synthetic biology, nonlinear dynamics, complexity science and computer science) in order to assess and highlight the problems of the metascientific and ideological foundations of diverse projects of prediction and control of uncertainty. From algorithmic surveillance back to cybernetics and how these rendered noise "informationally heretical". This conveys an analysis of how contemporary prediction technologies are dramatically transforming our relationship with the future and with uncertainty in a great number of our social structures. It is a philosophico-critical anthropology of data ontology and a critique of reductive pan-info-computationalism. Additionally, two practical examples of noise characterised as an enabling constraint for the functioning of complex adaptive systems are presented. These are at once biophysical and cognitive, : 1) interaction-dominance constituted by 'pink noise' and 2) noise as a source of variability that cells may exploit in (synthetic) biology.

Finally, noise is posited as an intractable active ontological randomness that limits the scope of determinism and that goes beyond unpredictability in any epistemological sense due to the insuperability of the situation in which epistemology finds itself following the critique of the given.

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Contents

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Introduction

> [A]s all the signals collapse into noise, a sub-primordial chaos entity will arrive.
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> Ccru
> *Channel Zero*
> (2017: 135)

> [T]he dream that leads to an eventual actual noise that wakens the dreamer.
>
> Goodman (1978: 81)

In 1931 Karl Jansky, a Bell Labs radio engineer, was assigned the job of investigating sources of static that might interfere with radio voice transmission and maximise the signal to noise ratio for the short-wave transatlantic radiotelephone. Jansky discovered that most of the static was caused by tropical thunderstorms, but additionally, he noted a continuous interference which changed direction over the course of the day. Listening to the static with headphones, Jansky described it as a hissing sound “that can hardly be distinguished from the receiver noise” (Hockey et al., 2014: 587). He found not just a clear instance of “noise *in* noise”, but an ‘extraterrestrial noise’ that inaugurated radio astronomy and revolutionised our ideas of the universe. In 1964, Arno Penzias and Robert Wilson, also engineers with Bell Labs tasked with tracking down radio noise, discovered the smoking gun of the Big Bang, the Cosmic Microwave Background (CMBR), in the process gathering the first experimental evidence that established the Big Bang model of the origin of the universe. This shattering reverberates through the ages down to the present day.

The only thing we have left from the origin of the universe is the CMBR as a faint background noise. A sonic fossil, nearly 14 billion years old, echoing through the cosmos as a huge, magnetic recording of the ‘foundational’ explosion, each echo transformed by its new environment.

If order and life counter chaos, they are nevertheless conceived from it. This is the *aporia* of all structure and life, not only in the noisy perturbation in our antennas, but in the very "cosmological perturbation"[1] as such, for what is the universe but an endless self-reproducing chaotic process, in which forces thrust back and forth with abrasive efficiency, gravity binds together hundreds of galaxies as if they were silk gauzes moved by the wind, while dark energy accelerates the expansion of a universe that, according to some, "wipes out [the] traces of its own origins" (Krauss and Scherrer, 2008: 47). Yet it will be the contention of this thesis that, from out of this prodigious uproar arise worlds on which vastly rich and complex forms will grow.

In our own day, the significance of noise to information and communication theory, cybernetics, its relation to thermodynamics, dynamic systems theory, evolutionary biology, complexity theory, theory of computation etc., has resulted in a vast array of new research contributions across different and multiple scientific disciplines. This has prompted under-theorized transpositions between fields, recasting ideas in their different application areas, that even exhibiting granular levels of detail, demonstrating in turn the failure to achieve a cohesive and comprehensive definition of noise. Thus, while we could define the number *1* or a curve as idealised mathematical objects[2], it is unlikely that we could say the same about noise because, I will argue: *noise* (just like nature) is a complex and extraordinarily high-dimensional notion. There is no attribute constituting an ideal object. Noise is both internally generated (subjectivity renders artworks into 'noisy' systems, since it is irreducible to the work in which it is ineliminably an element), and 'arrives' from the outside –e.g. effective recognition and modeling can occur even in noisy environments. Not only are the phenomena of noise pervasive throughout all transmissions (of information, energy, etc.); its presence is a prerequisite of any system both because it is ineliminably entailed by any functioning system (there is no such thing as a clear channel) but also because there would be no systems without noise. For instance, we cannot have photographic processing without the optical noise due to film grain, i.e. its *structure*. Moreover, it is impossible to conceive film photography without the possibility of the film turning out completely foggy. In the *resolution of uncertainty* that information entails, there *must* be the *chance* of a result completely 'perturbed' by noise. As we will see, this chance is *irreducible*. Ultimately, this is responsible for the gene mutation

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[1] The cosmological perturbation theory is the theory by which the evolution of structure is understood in the Big Bang model. See: Fry, J.N. (1984). The Galaxy correlation hierarchy in perturbation theory. *The Astrophysical Journal*. 279: 499.

[2] The ontological status of mathematical objects has been the subject of much research and discussion by philosophers of mathematics. See: Burgess, J. and Rosen, G. (1997) *A Subject with No Object: Strategies for Nominalistic Reconstrual of Mathematics*. Oxford: Oxford University Press.

that might *improve* or *deteriorate* the fitness of the organism or the symmetry breaking from which the Big Bang's unified electromagnetic forces may have *shattered* into the distinct forces observed today[3].

But how to categorise noise phenomena? In many regards this seems like an absurd operation. In the first place: should we categorise noise manifestations or noise causes? The more 'practically oriented' scholar would prefer noise causes, while the morphologist would try to classify the different phenomena as they emerge. The latter rapidly ends in a 'Russian doll-chaos'; what, for example, to make of bacteria coupling noisy gene expression with noisy growth in order to survive rapidly changing environments?[4] Identifying noise types by their causes alone is prone to error because noise is relative to information processing dynamics (Wilkins, 2021). Additionally, there are many noise phenomena whose causes we have as yet no knowledge of, while for others we may have the incorrect causes in mind[5], and many others we may never know their causes. Thus, I think a systematic characterization of all noise phenomena is extremely challenging and even futile. Noise is "lived ambiguity" (Malaspina, 2018: 168), it is the paradoxical dichotomy illuminated by the quotations heading this text: the redshift fragmentation of collapsed structures and the trigger of cascading processes of organisation and life. Noise pushes the boundaries of our human perception because there is something in it "that goes beyond our conceptual categorisation. It's not properly indexed yet and we don't have the right tools to deal with it. Either there is something wrong, or it actually shows our inadequacy to deal with reality" (Mattin, 2017: 93).

This thesis considers the epistemic consequence not merely of the ineliminability of noise but of its originative power –in effect, *poiesis* as a new, Goodman-based[6] solution to what Sellars called the "myth of the given"[7]. The myth is that something is given to know. If this is mythic

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[3] See: the Nobel Prize in Physics 2008, one half awarded to Yoichiro Nambu "for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics", the other half jointly to Makoto Kobayashi and Toshihide Maskawa "for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature." The Nobel Foundation. [online] Available from: https://www.nobelprize.org/uploads/2018/06/nobelguide_phy.pdf [Accessed 6 September 2020]

[4] See: Patange, O., Schwall, C., Jones, M. et al. (2018) *Escherichia coli* can survive stress by noisy growth modulation. *Nat Commun* 9, 5333.

[5] As will possibly be corroborated by forthcoming research. See: Amiri, M., Andersen, B., Bandura, K. et al. (2020) Periodic activity from a fast radio burst source. *Nature* 582. pp. 351–355.

[6] See: Goodman, 1978.

[7] See: Sellars, Wilfrid (1997) *Empiricism and the Philosophy of Mind. Introduction by Richard Rorty. Study Guide by Robert Brandom*. Cambridge: Harvard University Press.

rather than true, the myth disguises not only the character of our knowing, but also the nature of what is; if not given - then produced: Goodman's case responds, we could say, to a Kantian story (1993) about givenness being eliminated by manufacture with a worldmaker's story about knowing as making: the world known is by definition different to a world unknown, or a world painted or sung; yet all are 'poieses', so to speak. The argument presented here, implies that what is exceeds our grasp of it, but our grasping of what Badiou, referencing Deleuze, calls *The Clamour of Being*[8], synthesizes new being in turn. In other words, what this thesis will call "noxiogenesis" means that epistemology does not represent so much as create in accordance with a noisy cosmos.

In the last two decades, much has been written about noise under the domain of cultural theory, sound and media studies, aesthetics and critical theory. Recent contributions to the field include: Hegarty, 2007; Bijsterveld, 2008; Mattin and Iles, 2009; Kelly, 2009; Voegelin, 2010; Nunes, 2010; Krapp, 2011; Nechvatal, 2011; Schwartz, 2011; Goddard, Halligan and Hegarty, 2012; Hainge, 2013; Mattin, 2017. Lately, rigorous and systematic attempts at rehabilitating noise as a concept are taking place, Cecile Malaspina's *An Epistemology of Noise* (2018) and Inigo Wilkins' *Irreversible Noise* (2020) are major contributions to the understanding of noise as a multi-scale phenomena relevant to contemporary scientific and philosophical problems.

This thesis differs from the existing literature covering noise in culture, and with regards to science and technology. Our investigation cannot just involve the further clarification of certain principles. We present the prospect of different "contextures" of *a* present made volatile by noise. In a moment in which as a species we exhibit the capacity of global-scale coordination and the design of robust, adaptable social systems, we need to review the way in which we can harness *uncertainty*, *randomness*, *noise*. Thus, to emergently construct solutions to challenges such as the hidden regimes of algorithmic complexity that model our societies, the Anthropocene extinction, or the contraction of the future via technoscience.

Thesis statement

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[8] Badiou, A. (1999) *Deleuze: The Clamor of Being*. Minneapolis, Minnesota: University of Minnesota Press.

The argument of this thesis will be that *noise* is a multi-value irreducible process understood as ontological precondition for any ordered process of individuation to emerge, a permanent transformation of possibilities in actuality. This thesis will advocate a process metaphysics of "noxiogenesis" in contrast to the idealised discrete-state metaphysics of info-computationalist pictures of the world. These pictures, themselves the results of technoscientific models of capitalism, are incapable of affording a sufficient account of the "noxiopoietic" increase in the production of complexity (that permeates any region of the cosmos: from human culture to planetary nebula) for which this thesis argues.

Chapter overview

Chapter 1 begins by presenting the different scientific conceptions of noise over the last two centuries. This chapter provides an overview of the evolution and employment of the notion starting from an examination of noise's origins in Brownian motion as a form of randomness and its role as fundamental limitation on measurements. We will then take into consideration the different characterizations of entropy, from the different technoscientific fields and their models of control and prediction (thermodynamics, information theory, cybernetics, algorithmic information theory and dynamical systems theory) and the way in which it is presented in reference to noise. The chapter aims to supply not just a recapitulation of scientific discoveries and positions, but a critical philosophical departure based on the irresolvable incompleteness of a system that negates the discreteness or monocontextuality of its own history.

Chapter 2 undertakes a detailed genealogy of randomness and probability. The way in which they partake in the history of the concept of noise will be elucidated. The contrasting characterisations of epistemic and ontic randomness will be delineated. This "conceptual dissection" is vital in order to understand the difference between noise as an ontological or psychological phenomenon, between the calculation of objective probabilities and subjective judgement (Wilkins, 2021). The chapter will unfold the consequences of the subordination of chance to the status of an "empty concept" (Thom, 1983: 19) and the blind faith in deterministic processes in contrast to the construction of a scientific image that on the basis of measurement itself brings irreversibility and randomness.

Chapter 3 focuses on the development and application of Gilbert Simondon's realist philosophy of individuation. This chapter will develop an account of noise as *ontological* *precondition for morphogenesis*, or what I here call “noxiogenesis”, in line with Simondon’s theory of individuation through “transduction” (which entails a re-conception of information theory with thermodynamics) in a “metastable” “pre-individual” state space. Simondon’s philosophy poses an articulation of the different physical, vital and psycho-social regimes in conjunction with technology in a unified conception of the genesis and transformation of form.

Chapter 4 explore how the alleged non-rational, esoteric and even mysterious forms of divination and prediction in ancient cultures relate to algorithmic prediction as a form of knowledge-production, presenting a critique of algorithmic/computational “microfundamentalism”. In a contribution towards a philosophico-critical anthropology of data ontology, the chapter will examine the predictive power of algorithms and the underlying logic of divination, both in strong connexion with the ‘invocation’ of chance and randomness: from the mantic arts in medieval China to the production of *a* future (the calculation of “futurability”) through e.g. cryptography or climate modelling.

Chapter 5 aims to contribute to the broadening and expansion of the cognitive-enhancement and neuroethics debates by focusing on a particular form of relation or coupling between humans and cognitive artefacts: interaction-dominance. Interaction-dominance is both indicated and constituted by the phenomenon of “pink noise”. Understanding the role of noise in this regard will establish a necessary theoretical groundwork for approaching the ethical and political dimensions of relations between human cognition and digital cognitive artefacts. We argue that pink noise in this context plays a salient role in the practical, ethical, and political evaluation of coupling relations between humans and cognitive artefacts, and subsequently in the responsible innovation of cognitive artefacts and human-artefact interfaces.

Chapter 6 explores the functional role of noise in synthetic biology and its relation to the concept of randomness. Ongoing developments in the field of synthetic biology are pursuing the re-organisation and control of biological components to make functional devices. This chapter addresses the distinction between noise and randomness in reference to the functional relationships that each may play in the evolution of living and/or synthetic systems. The differentiation between noise and randomness in its constructive role, that is, between noise as a perturbation in routine behaviours and noise as a source of variability that cells may exploit, indicates the need for a clarification and rectification (whenever necessary) of the conflicting uses of the notion of noise in the studies of the so-called noise biology.

The aim of the final **chapter 7** is to **a)** present an alternative characterisation of noise as “noxiopoiesis”: a process of increasing production of complexity reliant on context sensitive enabling constraints. This strongly contrasts with the limited picture provided by the use of computational metaphors in the ever-increasing speed and complexity of our current world. That is, to contribute with **b)** a critique of “pancomputationalism” in which noise’s irreducibility to discreteness is patent. By this stage of the thesis we will have developed a detailed account of how “noise”, brings about a persistent perturbation to the system at the same time that makes it possible to explore a “global state-space” favoring a process-metaphysics or “noxiogenetic” account of complexity.

Chapter 1: (ᾰ̓)history of Noise

1.1: Introduction to the Chapter

When you start to think about the words to use when describing the history of noise, you are to some extent creating the history of noise. As these are its first lines in this new inquiry providing “perspective” on the problems of its present, we should treat its lineage as historical and therefore: amenable to a scientific treatment.

I would like to provide an account of the (ᾰ̓)history of noise on the basis of “asystasy” i.e. lack-of-system or “incompleteness” (Grant, 2007). I maintain that the history of noise is alpha-privative of systems[9]. Nature is modes of operation and among these modes of operation we find the consequent emergence of a system from “asystasy” (Schelling, 1997: 210). This emergence does not cancel asystasy but rather makes asystasy work in any given system. The *copula*[10] exposes the impossibility of any system which could be complete in itself, and this *asystasia*[11] which precedes the system as external ground “is nothing—not something, this itself would at least only be a negative definition. It is also not nothing, that is, it is everything” (IPU: 17). The positing of the asystasia calls upon the contention that “The need for harmony first comes out of disharmony” (IPU: 9), that is to say that the understanding of system, as such, has its basis in the disharmonic incompatibility of the plurality of systems in the preceding knowledge of them; a basis in prior incoherence. This means that we can posit an account of the history of noise that draws upon both the interference in a system and the irrepressibility of the asystasy. Once given, the asystasy cannot be suppressed by a system that includes it, rather it must be the case that asystasy exceeds the attempt of any system to include it. Noise is an instance of this process.

The aim of this chapter is to provide an elementary overview of the scientific facts of noise as a form of randomness (starting from its origins in the study of Brownian motion [**1.2**]), fundamental limitation on measurements (**1.3**), fluctuations or other sources of variability. Providing a synthesis of the historical development of the term (mostly) over the last two hundred years. Noise is one of the most slippery and evasive phenomenon to tackle in nature. Having said this, I am already professing my aim to disagree fundamentally with Thom’s (1983) assessment of the problem of the psychology-versus-ontology issue of noise –as we will see in detail through the course of this thesis. The fact is that since the latter term encompasses the former but the reverse is not true, this demands the subjective/objective status of noise be revised.

We are going to address literature stemming from a cluster of interrelated and interdependent scientific disciplines united by the schism of the different characterizations of entropy. Starting from its roots in the field of thermodynamics (**1.4** & **1.5**), entropy has been described

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[9] “[T]he same dynamic asymmetry of productivity and product arises in transcendental philosophy as in nature.” (Grant, 2006: 180)

[10] “[T]he copula provokes an iteration of identity without end or issue, wherein each iteration differs from its antecedent and its consequent, but consequently upon differentiation.” (Grant, 2015: 115)

[11] “Taxis” as order, “sys” as combination, and the alpha-privative as the negation, therefore, of a state of ordered combination.

as *the number of microscopic degrees of freedom* in statistical mechanics (**1.6**), *the measure of information* in information theory (**1.7**), *the opposite of information* in cybernetics (**1.8**), the *length of the shortest algorithm* that specifies the system's exact state in algorithmic information theory (**1.9**) or in the case of systems theory (**1.10**) *the tendency for a systems' outputs to decline* when the inputs have remained the same. As we will examine in detail in chapter 2, all these fields fall under the umbrella of "objective", "physical" or "frequential" probability. They are associated with the study of random physical systems and the measure of the *real*, physical tendency of something to take place.

Acoustic noise is not going to be addressed in this brief genealogy as from a physical point of view, noise is indistinguishable from any other sound, as all are longitudinal, mechanical waves (oscillations of matter) traveling through a medium.

We tend to gravitate towards the constant disputes around the use of the term noise . But why should we care about the definition of noise in the first place?

Arguably, noise and fluctuations are at the basis of all physical processes. It is a rather notorious fact that noise plays a disruptive role in linear systems[12]. Nonetheless (even before the discoveries on nonlinear systems), we can recognize noise providing positive contributions. In some cases, information transfer can be optimized at nonzero noise levels or noise as such can tell us useful information about the system itself. This indicates that the issue "what is noise" is of more than scholarly significance. If we circumscribe noise to the domain of data we exclude, then we are required to provide a model that explicates the remnant data. If not, this implies that noise is indeed carrying relevant information.

Finally, we will see how the potentially productive role of noise was theoretically explored (sometimes leading to a rather irrational devotion to the term) by some of the members of the so-called Groupe des Dix (**1.11**) on the background of cybernetics, systems theory and information theory.

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[12] See for instance: Gersho A. and Gray R.M. (1992) Random Processes and Linear Systems. In: Vector Quantization and Signal Compression. The Springer International Series in Engineering and Computer Science (Communications and Information Theory), vol 159. Boston: Springer.

Noise may be equivocal with non-deterministic processes since the concept of noise is also used as an umbrella term for unexplained deterministic phenomena –unpredicted environmental turbulences alter a measurement. An examination of this type of noise on purely statistical grounds may lead to practical as well as conceptual problems. As mentioned, we will see this in the next chapter.

1.2: Atomism and Brownian Motion

As discussed by Schelling in Lecture 18 of the *Philosophical Introduction to the Philosophy of Mythology* (SW XI, 427; 1847-52), Brownian motion is the fluttering motion of particles in fluids, they are not standing still, but moving around in all sorts of random directions. We can see this by looking at pollen grains under a microscope, floating in water. The botanist Robert Brown did not discover Brownian motion, the phenomena had been known as least since the ancient Greeks[13], but he studied it thoughtfully, in 1827 Brown first described the motion in detail[14]. He was not able to determine the mechanisms that caused the motion he saw while looking through the microscope, but he proved that it was not caused by some living organism. While there were conjectures that the motion was a product of the collision of atoms against the particles, it was not confirmed until Einstein published "On the Movement of Small Particles Suspended in Stationary Liquids Required by the Molecular-Kinetic Theory of Heat" in 1905[15]. He provided a detailed account of how the motion that Brown had observed, was a consequence of the pollen being moved by individual water molecules. This explication of Brownian motion renders a trustworthy confirmation that atoms and molecules do exist. However, it is extremely interesting to note how philosophers and scientists have disputed whether noise as a form of randomness really exists (what is its origin, or whether we use this term only to model phenomena) since ancient times. Epicurus (341–270 BC) asserted that its origin lay in the 'swerve', a concept already emergent in Democritus (460–

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[13] See: DK 67A14; KRS 557, 584; T 57. The opinion of Leucippus, Democritus, and Epicurus on the first principles was that atomic bodies are in motion in the void, and that as they overtake one another they collide, and that while some rebound in random directions (Simplicius (1894) *Commentary on Aristotle's 'On the Heavens'*, ed. J. L. Heiberg, CAG VII, 242.18–26).

[14] Brown, R. (1828) Xxvii. a Brief Account of Microscopical Observations Made in the Months of June, July and August 1827, on the Particles Contained in the Pollen of Plants; and on the General Existence of Active Molecules in Organic and Inorganic Bodies. *The Philosophical Magazine, Series 2*. 4 (21), pp. 161-173.

[15] Einstein, A. (1905) Über Die Von Der Molekularkinetischen Theorie Der Wärme Geforderte Bewegung Von in Ruhenden Flüssigkeiten Suspendierten Teilchen. Annalen Der Physik. 322 (8). pp. 549-560.

370 BC). Epicurus (allegedly[16]) claimed that “randomness is objective, it is the proper nature of events”. He argues that true randomness exists and it is built-in nature, independent from human knowledge.

The primordial account of what strikes us as being a prophecy of the fluctuations of Brownian motion is narrated in the second book of Lucretius’s poem *De rerum natura*. As a primary source of information on Epicurean physics, Lucretius’ account of the atomic ‘swerve’ or ‘clinamen’[17] portrays the deviation of the particles that brings them into excited motion. He represents these random fluctuations with the example of motes in a sunbeam:

> Just look when sunbeams shine in a darkened room,
> you will see many tiny objects twisting and turning
> and moving here and there where the sunlight shows.
> It is as though there were an unending conflict
> With squadrons coming and going in ceaseless battle,
> Now forming groups, now scattering, of nothing lasting.
> (Lucretius, 1976: 47)

This illustrates the regular opposing directions observed in the motion of lighter and heavier substances when the random atomic movements are organised into a more or less uniform current. Such current was understood by Democritus as arising out of chance turbulences evolving into vortices (Konstan, 1979). But Democritus acknowledged the need to account for this disorderly movement of individual and distinct atoms as producing an orderly cosmos. In contrast to Epicurus, Democritus asserted that ἄνθρωποι τύχης εἴδωλον ἐπλάσαντο πρόφασιν ἰδίης ἀβουλίης. βαιὰ γὰρ φρονήσει τύχη μάχεται, τὰ δὲ πλεῖστα ἐν βίωι εὐξύνετος ὀξυδερκείη κατιθύνει. (DK 68 B 119) “Men have made an idol of Chance as an

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[16] See: Hromkovič, J. (2009) *Algorithmic Adventures: From Knowledge to Magic*. Berlin: Springer, p. 205., Gruska, J. (2010) Universe as a Quantum Computer. *Quantum Computing* [online]., p. 68. [Accessed 12 October 2019]., Calude, C and Longo, G. (2016) Classical, quantum and biological randomness as relative unpredictability. *Natural Computing*, 15, Berlin: Springer, pp.263 – 278.

[17] Karl Marx saw in the clinamen a cosmological justification of chance and thus human freedom. See his university thesis: “The Difference Between the Democritean and Epicurean Philosophy of Nature” in Marx, K. (1902) *Marx-Engels Collected Works Volume 1*, Moscow: Progress Publishers.

excuse for their own incompetence; for chance disrupts planning a little, but intelligent foresight straightens out most problems in life.” (Graham, 2010: 642-3)

Democritus provides a glimpse into the future of René Thom’s 1983 paper “Stop Chance! Silence Noise!”:

> I would like to say straight out that this fascination with randomness testifies to an antiscientific attitude par excellence. Moreover, in a large measure, it proceeds from a certain deliberate mental confusion, excusable in writers of literary formation, but difficult to pardon in men of science who in principle have been trained in the rigors of scientific rationality. (1983: 11)

Thom refers to chance as a subjective phenomenon, affecting only the psychology of the inquirer, as the consequence of the incompleteness of our knowledge. According to this view, noise and randomness pertain only to our processes of conceptualisation and measurement. There are, however, factors determining the course of every process, even if we cannot measure or control them precisely. If there are such factors, however, where do they obtain? Calude and Longo contend that “randomness is not in the world nor is it just in the eyes of the beholder, but it pops out at the interface between us and the world by theory *and* measurement” (2016: 4). This alerts us to the problem of situating noise, whether as a subjective or a fundamental limit to physical measuring processes.

On the objective side of this problem, Alder van der Ziel (1910–1991), Dutch physicist and pioneering researcher of noise, in his electrical engineering book *Noise* (1954) explains how spontaneous fluctuations are revealed as of practical importance for measurements. Noise establishes the lower limit of a signal which can be detected, it limits the accuracy of different kinds of measurements and is a practical concern of experimental physicists and electrical engineers (van der Ziel, 1954). Van der Ziel mentions how the Swedish physicist Gustaf A. Ising (1883–1960) identified in 1925 that spontaneous fluctuations establish a limit on the sensitivity of galvanometers (the first instruments used to determine the presence, direction, and strength of an electric current), and that this limit is not difficult to reach in experimental situations. Spontaneous fluctuations about the steady state are considered a more scientific approximation to the idea of noise in these early steps in the history of its research. These pioneer investigators of noise likened those fluctuations of current and voltage in electric circuits to Brownian motion (van der Ziel, 1954).

It is known that a particle moving in a vortex of potentials under the influence of random forces exhibits fluctuations. A major point of the development of the Brownian motion theories that Albert Einstein and Marian von Smoluchowski carry through at the beginning of the twentieth century is its role as a leading aspect in the modelling of noise.

Einstein's 1905 paper addresses a property of fluids called 'diffusion'. He put some pigment emulsion in water, and this spread out over time. This is as a result of the colouring buzzing around with the water molecules. Due to the fact that the random motion was indeed generated by molecular collisions, the colour will move with a pattern known as a 'random walk', which refers to any process in which there is no observable pattern or trend. Typically, the position of the colouring remains unchanged, but some will drift outward by chance. This shows how the colouring diffuses in the course of time. What Einstein revealed was that the diffusion of a particle exposed to Brownian motion will diffuse at a particular rate and that this rate is determined by the number of atoms or molecules in a mole of the substance in which the particle is suspended, that is, find Avogadro's number. From here, he was able to measure the size of molecules or atoms. A measurable quantity that gave us evidence of the atomic domain.

Einstein's 1905 paper (and Marian Smoluchowski's independent article in 1906) contributed to an unprecedented theory for the existence of atoms, culminating in Jean Perrin's groundwork of experimental confirmation for such otherwise hypothetical bodies (later awarded with the Nobel Prize in Physics in 1926[18]). Brownian motion presented: a reformulation of statistical mechanics, the evidence for atomism and the production of new mathematical methods, methods which in turn were the foundation of the formalisation of stochastic processes that would come to play a key role in fields as varied as: designing gun-control systems, financial decision making, predicting climate change or modelling biological evolution[19]. Still, one of the most salient contributions of Brownian motion is the understanding and effects of electronic noise.

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[18] Jean Perrin paid homage to the ancient atomists in his Nobel acceptance speech of 1926.

[19] See, for example: Bigg, C. (2005) Brownian motion, In *Albert Einstein: Chief Engineer of the Universe*, ed. Jiirgen Renn, Weinheim: Wiley-VCH, pp. 120-123., Bigg, C. (2008) Evident atoms: Visuality in Jean Perrin's Brownian motion research. *Studies in the History and Philosophy of Science* 39 (3):3. pp. 312-322., von Plato, J. (1998) *Creating modern probability: Its mathematics, physics, and philosophy in historical perspective.* Cambridge: Cambridge University, pp. 123-136., Maiocchi, R. (1990) The case of Brownian Motion. *The British Journal for the History of Science* 23, 3. pp. 257-283., Stachel, J, Cassidy, D, Renn, J and Schulmann, R (1990) Einstein on Brownian Motion. In *The collected papers of Albert Einstein, Volume 2: The Swiss years:*

1.3: Noise as a Fundamental Limitation on Measurements

The early theoretical analysis of electrons as Brownian particles appeared in 1912, by G. L. de Haas-Lorentz[20] which motivated G.A. Ising, in 1925, to exhaustively elaborate on the problem of galvanometer fluctuations[21] detected by Moll and Burger[22]. During the 1920s, Ising and his peers conducted experiments and studied the role of the theory of Brownian motion in the modelling and rationale of the widespread assertion (between these scientists) that there is a limit to all physical measuring processes. They considered the effect of Brownian motion on specific parts of the measuring instruments[23].

Thanks to J. J. Thomson's discovery and identification of the electron in 1897 as well as P. K. L. Drude's classical model of electrical conduction corresponding to an electron gas in an atomic lattice (both firmly ingrained principles in physics at that point in time) the acquired science was ready for the understanding of electrical noise. J. B. Johnson (following W. Schottky's work of 1918[24]) started in 1925 to determine the thermal noise in various conductors via a vacuum tube amplifier and presented his widely-known formula for voltage noise[25] in 1927-28, which is tantamount to Einstein's fluctuation formula for Brownian motion of charge (Abbott et. al., 1996). Johnson reviewed his results with H. Nyquist, who, about a month later, succeed in the composition of a notably succinct theoretical derivation centred on the thermodynamics of a transmission line[26]. He applied the equipartition theorem of statistical mechanics to the transmission line modes. Fluctuations are the result of a basic principle of equilibrium in statistical mechanics and one of the fundamental theorems of thermodynamics is the *equipartition theorem*.

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writings, 1900-1909, ed. Stachel et al., Princeton: Princeton University Press. pp. 206-222. and Cohen, L. (2005) The history of noise: On the 100th anniversary of its birth. *IEEE Signal Processing Magazine* 22, 6. pp. 20-45.

[20] De Haas-lorentz, G.L. (1913) *Die Brownsche Bewegung Und Einige Verwandte Erscheinungen*. Wiesbaden: Vieweg+teubner Verlag.

[21] Ising, G.A. (1925) A natural limit for the sensibility of galvanometers. *Phil. Mag*. 51. pp. 827-834.

[22] Moll, W.J.H and Burger, H.C. (1926) The sensitivity of a galvanometer and its amplification. *Phil. Mag*. 51. pp. 626-631.

[23] See, for example: Van Lear Jr., G.A. (1933) The Brownian Motion of the Resonance Radiometer. *Review of Scientific Instruments*. 4, 21. pp. 21-27

[24] Schottky, W. (1918) Uber spontane stromschwankungen in verschiedenen electrizitatsleitem. *Ann. Phys*. 57. pp. 541-567.

[25] Johnson, J.B. (1928) Thermal agitation of electricity in conductors. *Phys. Rev*. 32. pp. 97-109.

[26] Nyquist, H. (1928) Thermal agitation of electric charge in conductors. *Phys. Rev*. 32. pp. 110-113.

The equipartition theorem states that energy is distributed equally between all energetically accessible degrees of freedom of a system. This might not sound like an unexpected insight; it can be understood as another way of stating that a system will generally try to maximise its entropy (i.e. how dispersed the energy is in the system) by sharing the available energy evenly between all the available modes of motion. As an example, think about a closed vessel in which we have placed a number of marble balls. Initially the marbles are stationary. Suppose we now introduce some energy randomly into the vessel, which will be shared out between the marbles in a way such that they begin to travel around. Intuitively we know what this movement would look like: completely random motion of the marbles. This is precisely the same result provided by the equipartition theorem: the energy is shared out equally between the x, y, and z translational degrees of freedom – which can be thought of as moving forward or backward, moving left or right, and moving up or down. The fluctuations described by the equipartition theorem cause electrical noise as we know it. Hence this type of noise is called Nyquist noise, Johnson noise, or Thermal noise.

Thanks to the developments during and after the Second World War, Ising's general conclusion was related to the notion of noise, reframed, with noise stabilising a limit on physical measurement processes. While the physicist N. F. Astbury discussed the "inherent 'noise level' of a galvanometer" (Astbury, 1948: 593), the chemist E. Bright Wilson wrote under the heading "Noise as a fundamental limitation on all measurements" in his workbook on scientific research:

> With the availability of modern amplifying equipment [...] it might seem as if there were no limits to the sensitivity and accuracy with which measurements could be made. Actually, this is not correct, because practically all measurements are limited by thermal fluctuations or by similar phenomena. From the importance of these disturbances in producing background signals in radio, the term noise is often used for all of them. (Wilson, 1952: 116)

Very close to this account, van der Ziel stated: "If the sensitivity of measurements is pushed higher and higher it finally is limited by noise." (van der Ziel, 1954: 403). But, going a step further, van der Ziel conceived the limit result with regards to signals: "In most measurements we have a signal source, which produces the quantity (signal) to be measured, an indicating instrument, which measures it, and means by which the signal is supplied to the indicating instrument. Noise sources may occur at any point." (ibid.). Following those realisations, Ising's conclusions were integrated into a more generalized notion of noise. In addition to the epistemological relevance for measurements in physics, it is a milestone in the history of noise, insofar as it was the first time that the connection of Brownian motion to an experimental problem in physics was demonstrated numerically (Bowling Barnes and Silverman, 1934). Noise has not only theoretical importance but important applicability.

As a matter of fact, noise produced by apparatus is conditioned by their design and performance, some noise sources are determined by the technology employed in manufacturing the device and, in theory, by improving the technology, it could be removed. Noise reigns over two kingdoms: the *subjective*; constructive nature of perception and the *objectivity* of chance in nature. The latter is reflected in 'fundamental noise'[27] as intrinsic and inevitable, inherent in the main kinetic processes in a given device as well as irreducible.

Although these early studies were initiated to set out the fundamental operation limit of electronic technology, they ended up facilitating the understanding of empirical determination. Noise describes the limits of experimental sensitivity; Brownian noise was widely conceived of as the fundamental obstacle to the precision of measurement. The aporetic situation that we face is that the physics of fluctuations (noise) result from the fact that the ultimate exactitude of measurement (of any physical quantity) is constrained just by fluctuations (of this quantity), and the furthermost sensitivity of many instruments is also limited by noise. Measurements can just turn uncertainty (quantified as we will see by statistical entropy) into randomness of the outcome (determined –as it will be explained– by the algorithmic information content of the data). The capacity to obtain useful work is measured by physical entropy, which is equal to the sum of these two measures of disorder. Thus, we need to step back in time and pay attention to the development of thermodynamics. It seems counterintuitive now, but, despite the fact that the notions of atoms and molecules are now completely accepted, this was not true at the turn of the twentieth century. Einstein was confessedly unaware of Boltzmann and Gibbs' investigations on the second law of

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[27] Is understood as fundamental noise, noise as a result of fundamental physical processes and quantities such as the ambient temperature, circuit resistance, and the discrete nature of electric charge. Two common types of fundamental noise are "Johnson" and "shot" noise. Both are derived from fundamental physics and since this physics involves fundamental constants, one can, in fact, use measurements of noise to obtain experimental values of these constants. See: Johnson, J. B (1928) Thermal agitation of electricity in conductors. *Phys. Rev.* 32, pp. 97-109, and Schottky, W (1918) Uber spontane stromschwankungen in verschiedenen electrizitatsleitem. *Ann. Phys*. 57, pp. 541-567.

thermodynamics (1949: 47), and he had to develop his own form of statistical mechanics based on atoms and mechanics. The importance of the theory lay in the fact that it confirmed the kinetic theory's account of the second law of thermodynamics as being an essentially statistical law (Clark, 1976).

1.4: A Profane Thermal Transubstantiation

> Not Copernicus and Galilei [sic], when they abolished the Ptolemaic system; not Newton, when he annihilated the Cartesian vortices; not Young and Fresnel, when they exploded the Corpuscular Theory; not Faraday and Clerk-Maxwell, in their splendid victory over *Actio in distans* – more thoroughly shattered a malignant and dangerous heresy, than did Joule when he overthrew the baleful giant force, and firmly established, by lawful means, the beneficent rule of the rightful monarch, energy! Then, and not till then, were the marvellous achievements of Sadi Carnot rendered fully available; and Science silently underwent a revolution more swift and more tremendous than ever befell a nation. But this must be a theme for the Poet of the Future!
>
> (Anonymous, 1884, review of Joule's Scientific papers in the Phil. Mag, quoted in Smith, 1998: 1)

If entropy is 'born' as a "unified quantitative measure of dynamical randomness to both chaos and noises" (Gaspard and Wang, 1993: 291), its birthing from thermodynamics is completely linked to the invention of the steam engine, the search for maximum performance, tied to the ideals of 'perfection' from the French Revolution. In its birth, the great changes and upheavals that occurred in the Western world during the nineteenth century are reflected: thermodynamics is the science of the industrial revolution, the construction of a knowledge that bows the second discovery of the power of fire by mankind. From a wider perspective, it would not be wholly inaccurate to suggest that thermodynamics is tied to a more general mindset that had been growing in the West throughout the 18th Century and into the 19th. The industrial revolution, the idea of "perfection" in moral philosophy, and the whole-hearted belief that humankind had discovered the fundamental laws governing the natural world spurred a fascination in energy, modes of productivity and motion, and decay. "The nineteenth century", in this way, "found its essential mythological resources in the second principle of thermodynamics" (Foucault 1986: 22).

The Greek word *entropia*, means “a turning toward” or “transformation”. The intellectual origins of the discipline can be found in Sadi Carnot’s seminal book published in 1824[28]. His research on steam engine efficiency resulted in what is now recognised as the ‘Carnot theorem’, whereby heat in steam engines tends to flow spontaneously and irreversibly from higher to lower temperatures (Carnot, 1824). The inability of any system to absorb entirely the universal in which it is situated, or to see it from a different angle, can also be understood through the classical thermodynamic perspective. According to this, in the production of equilibrium in a thermal context, entropy increases due to the dissipation of energy and the dispersal of matter and energy in accordance with the fundamental character of the *Second Law of Thermodynamics*. Steam engines cannot exceed a specific maximum efficiency. In the early 1850s, Rudolf Clausius developed the notion of a thermodynamic system and asserted the principle in which any irreversible process (based on the idea that there are no reversible processes in nature) a small amount of heat energy δQ is incrementally dissipated across the system boundary. In 1865 Clausius coined the term entropy[29], formed from Greek ἐν *en* “in” and τροπή *tropē* ‘transformation’ is ‘*content transformative*’ or ‘*transformation content*’ (‘*Verwandlungsinhalt*’), arguing the form of energy that in due course, and unavoidably turns into a useless heat. “I intentionally chose the word Entropy as similar as possible to the word Energy... The energy of the universe is constant; the entropy of the universe tends to a maximum (Clausius, 1867: 357). The far-reaching adoption of the notion of entropy in multiple fields lead to many inconsistencies and mischaracterisations pertaining to entropy. But the second law of thermodynamics is not absolute. As Boltzmann will show, it is a statement of probability, but with such a large number of atoms in the universe, the statistical average inevitably prevails.[30]

1.5: Applied Demonology

In 1867, James Clerk Maxwell applied the new microscopic knowledge about heat as random molecular motions to conjecture about a “pointsman for flying molecules” (Knott, 1911: 214-215) that could bend the laws of nature, particularly on the second law of thermodynamics

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[28] Carnot, S. (1824) *Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance*. Paris: Bachelier.

[29] Clausius, R. (1865) Ueber verschiedene für die Anwendung bequeme Formen der Hauptgleichungen der mechanischen Wärmetheorie, *Annalen der Physik*, 125, 7, pp. 353-400.

[30] Boltzmann, L. (1896/1898) Vorlesungen über Gastheorie, 2 vols. Leipzig [English translation by Stephen G. Brush: Boltzmann, L. (1995) Lectures on gas theory. New York: Dover. pp. 401-403.

by sitting at the passage between two chambers of gas and opens the door whenever either a relatively fast moving molecule moves towards it from B, or a relatively slow moving molecule moves towards it from A. This hypothetical being (baptised as “Maxwell's intelligent demon” by William Thomson (Lord Kevin) years later[31]) only lets hot molecules through to A and cold molecules through to B. “The hot system has got hotter and the cold colder and yet no work has been done, only the intelligence of a very observant and neat-fingered being has been employed” (ibid.). By splitting a gas of initially uniform average temperature into two chambers (one hot the other cold) a temperature gradient is generated and can then be employed to perform work. In that process, the entropy of the system decreases (randomness is reduced and order increases) in defiance of the second law’s precept that total entropy in an isolated system must always increase in any process of change. Maxwell’s lesson is that the basis for the second law is the statistical behaviour of vast numbers of molecules, and there is no sufficient technical leniency that can reverse these statistical patterns. As he illustrates to John Strutt (later Lord Rayleigh) in 1870: “The 2nd law of thermodynamics has the same degree of truth as the statement that if you throw a tumblerful of water into the sea, you cannot get the same tumblerful out again.” (1924: 47-8). The crux of Maxwell’s demon exorcism is how the Demon acquires and manipulates information by measurements. Maxwell’s demon mines thermal noise[32], he has information about the details of all the molecular motions that we do not have at the macroscopic scale. Information itself turns into means for doing work. The demon exploits classical thermal fluctuations as means for work because it has access to the information that exists within them, information inaccessible for us. He consumes the information distilling work from the energy contained in a thermodynamic system, information is consumed and disappears as part of the procedure for the beginning of a new series of performance If the operation is directed to arrange a perpetual motion machine of the second kind (a device that spontaneously converts thermal energy into mechanical work), the quantity of work employed in completing the operation (entailing the measurement, extraction of the work from the system, and deletion of information) should be inferior to the amount of work generated, thereby the total entropy of the universe decreases in the course of action. A demon ‘possessed’ by information could in principle lead to thermodynamic consequences. A

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[31] Thomson, W. (1874) The kinetic theory of the dissipation of energy. *Nature*. 9. pp. 441-444.

[32] See for instance: Ball, Phillip (2018) Putting quantum noise to work [online]. Available from: https://physicsworld.com/a/putting-quantum-noise-to-work/ [Accessed 16 June 2020]

cunning idea that in 1929[33], the Hungarian scientist Leo Szilard presented as the treatment of demon's intelligence as information and linked it with physics. Szilard's version of Maxwell's thought experiment, involved a single molecule in a box, in thermal contact with a heat bath, and a partition of two volumes. Thermal contact transfers energy, through random fluctuations, alternating between the molecule and the heat bath. The molecule ricochets randomly throughout the box with this thermal energy. Szilard argued that for the purpose of obtaining entropy reduction, the demon must procure information about which fluctuation occurs and so must execute a measurement, store that measurement's information in memory, and then employ the information to attach the moving partition to a weight as a means to get useful work. The second law would not be violated since there is a compensating cost of energy which the demon needs in order to measure molecule's position. In Maxwell's case to decide whether a molecule was moving fast or slowly. This binary decision process stands for one bit of information. Storing this bit, so that it can be acted on, requires energy. Szilard's thought experiment has a captivating implication, which is that information is, itself, a type of energy. Szilard anticipated the importance of the role of information associated with binary processes way before the existence of modern information notions and the computer age. In doing so he discovered what is now understood as information theoretic 'bit', the binary digit or 'bit' of information.

1.6: Thermodynamic Entropy and Its Relation to Probability

If Maxwell addressed the problem of entropic irreversibility by 'inviting' an imaginary 'demonic information processor', the scientists who linked entropy even further with information were Willard Gibbs and Ludwig Boltzmann, who 'planted an intellectual time bomb' in 1904 by characterizing entropy as 'missing information' (Campbell, 1984).

Ludwig Bolzmann who died in 1906, had his entropy equation $S = k \log W$ carved on his tombstone. His contribution was to formulate the second law of thermodynamics in terms of the probable arrangements of atoms and their energies. In this context, W is the number of arrangements that would give the same observed state at the macroscopic scale. In effect W is proportional to a probability and Boltzman is saying that the world tends to move to a more

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[33] Szilard, L (1929) Über die Entropieverminderung in einem thermodynamischen System bei Eingriffen intelligenter Wesen. *Zeitschrift für Physik*. 53, 11–12. pp. 840–856.

probable state. By deriving the second law mathematically he has arrived at a formulation similar to that later found for information transmission[34]. So is the measure of information and that of entropy the same thing, as some would have us believe? The answer is clearly not. Like all analogies, it is useful where it corresponds, but we must be careful not to deceive ourselves where it does not. For example, think about seven plastic tiles, each bearing a single letter, hanging on the wall. They spell the message “CAUTION” and now we can throw them to the floor. The message on the tiles is destroyed as they fall to the floor. They also convert their potential energy as falling objects into heat with an increase in entropy, but that is clearly not the same thing. Their thermodynamic result would have been the same even if I had mixed them to destroy the message before throwing them off the wall. One of the big differences is that information can be replicated. The information carried by these tiles has not been destroyed because several copies of it still exist in my mind and yours.

During the 1870s, Maxwell, Ludwig Boltzmann and Willard Gibbs introduced entropy into the probability theory realm of statistical mechanics. Boltzmann and Gibbs introduced statistical equations for thermodynamic entropy leading to the Boltzmann constant and Maxwell-Boltzmann distribution. Boltzmann created the notion of microstates and its relation to macroscopic entropy. A macrostate is something that we can easily measure. For example, a chamber full of gas will have its macrostate defined by its pressure, volume, number of particles, etc. These are easy variables to determine. A microstate will be the specific, exact state of that container of gas. This will include the exact position and momentum of every particle. As we can imagine, finding the microstate of a system is extremely difficult for a large enough system. A chamber will have many millions of gas particles, so knowing all of their positions and momenta is just not feasible.

Boltzmann characterised entropy as proportional to the natural register of the number of microstates, Ω – Boltzmann entropy. The proportionality constant is the Boltzmann constant

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[34] Boltzmann’s H-theorem (1966), exposes the way in which the irreversibility of entropy increase can be derived from the microscopic reversibility of processes following Newtonian mechanics. Boltzmann was convinced that the behaviour of the function $-H(t)$ is the same as that of the entropy, i.e., entropy always increases with time, and at equilibrium, it reaches a maximum. Once equilibrium is reached entropy does not change with time. Named after Boltzmann’s H-theorem, Shannon defined the entropy H (1948: 393) of a discrete random variable as $H=-K\sum ni=1pi\log pi$. Shannon’s formula can be understood as a generalization of the Boltzmann’s entropy S to a case with different probabilities of microstates or, under Shannon’s own approach, different probabilities of letters in a message.

k. To refer back to the equipartition of energy theorem, this states that a system of particles in equilibrium at absolute temperature *T* will have an average energy of $^{1}/_{2}kT$ associated with each degree of freedom in which *k* is the Boltzmann constant. The physical significance of *k* is that it provides a measure of the amount of energy (i.e., heat) corresponding to the random thermal motions of the particles making up a substance. Entropy (*S*) is a quantifiable measure of the dispersion of energy. The greater the number of microstates (they describe the configurations of the locations and momenta of particles in a system), the greater the entropy. Basically, the amount of microstates is a measure of the possible disorder of the system.

Boltzmann depicted particles, such as gas molecules colliding, like the marbles in a closed vessel. Each collision induces increasing disorder into the nonequilibrium velocity distributions (groups of molecules moving at the same speed and in the same direction), which result in a final state of maximum microscopic disorder and macroscopic uniformity, this is understood as the state of maximum entropy –the macrostate with the biggest number of accessible microstates. The distribution of velocities at a given temperature is a maximum entropy distribution – known as the Maxwell-Boltzmann distribution.

> As a result of collisions, many molecules will acquire larger velocities and others will come to have smaller velocities, until finally a distribution of velocities among the molecules is established such that it is not changed by further collisions [. . .] after a very long time the distribution of kinetic energy will become uniform. (Boltzmann, 1966: 91-94)

Maximum entropy and the second law, Boltzmann affirmed, are simply the result of the fact that in a world of mechanically colliding particles disordered states are the most probable (Boltzmann, 1974: 20-23). The fact that disordered states are much more probable than ordered ones (because there are many more ways in which a disordered state can be achieved, than an ordered one) in most cases, a system will tend towards (or being) in the state of maximum disorder – the macrostate with the greatest number of available microstates, such as a gas in a box at equilibrium. On the contrary, a dynamically ordered state, one with particles moving “at the same speed and in the same direction”, Boltzmann inferred, is thus “the most improbable case conceivable [...] an infinitely improbable configuration of energy” (Boltzmann, 1974: 22). Hence, Boltzmann “simplified” things by presenting probability theory as an “empirical device”, helpful in providing a more general comprehension of entropy as a measure of the randomness or disorder of a system. Boltzmann's entropy can be understood as "missing information", measuring the amount of "disorder" in a physical system. This missing information –below the threshold of possible measurement (Longo, 2009)–, this epistemically impenetrable difference; *is noise*. On the other hand, Gibbs entropy is the generalisation of the Boltzmann entropy ruling for all systems, while the Boltzmann entropy is only the entropy if the system is in global thermodynamical equilibrium. Both are a measure for the microstates available to a system, but the Gibbs entropy does not need the system to be in a single, well-defined macrostate. If we separate the macroscopic (Boltzmann) and statistical (Gibbs) approaches one can identify distinct concepts of equilibrium. Gibbs presented the notion of an ensemble –a group of many possible states of a system, each designated with a certain probability. He argued that if the time evolution of a single state were to come by all the other states in the ensemble (the so-called ergodic hypothesis) then averaged over a sufficiently long time a single state would function in a way that was usual of the ensemble. The microstate of one subsystem is conditionally independent of the microstates of other subsystems, given their macroscopic state variables. Gibbs entropy is basically Boltzmann entropy written as a sum of probabilities. The probabilities in the entropy formula are now taken as probabilities of the state of the whole system –i.e. the system in all of its states.

Classical thermodynamics had only taken into consideration the unstable states in non-equilibrium (that is, where a certain amount of potential energy is present. Meaning: energy that can do work) and the states of stable equilibrium (where there is no potential energy). In his study of science of materials, Gibbs (1928) introduces the notion of "metastable equilibrium" to account for certain special states of specific areas in which a certain minimum addition of energy external to the system causes a shift away from equilibrium. That is to say, an instability that eventually resolves into a 'disequilibrium' sustained by the constant input of energy –like constantly adding reagents and removing products from a chemical reaction. His theory is one of the crucial, almost defining, considerations of open systems. That there is a space "external to the system", which can irritate or provoke the system into transformation, and is tied to the critique of the "discrete model" in the American cybernetic literature.[35]

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[35] See: Pias, C. (Ed.), (2003) *Cybernetics – Kybernetik. The Macy-Conferences 1946-1953*. Zürich/Berlin: Diaphanes.

1.7: Turning Juggling into Information Theory

The story *is told* like this: in the early 1940s Claude Shannon showed his “information” formula to John von Neumann and he immediately made the connection with his own entropy function – an extension of classical Gibbs entropy to the field of quantum mechanics.

In 1961, Shannon told Myron Tribus that von Neumann was the person who encouraged him to name his new formula ‘entropy’. In the words of Tribus, Shannon recalled:

> My greatest concern was what to call it. I thought of calling it ‘information’, but the word was overly used, so I decided to call it ‘uncertainty’. When I discussed it with John von Neumann, he had a better idea. Von Neumann told me, ‘You should call it entropy, for two reasons. In the first place your uncertainty function has been used in statistical mechanics under that name. In the second place, and more importantly, no one knows what entropy really is, so in a debate you will always have the advantage.’” (Tribus and McIrving, 1971: 180)

Shannon did not remember von Neumann saying such a thing to him when asked twenty years later about this episode[36]. Maybe it was Norbert Wiener (one of Shannon’s teachers at MIT) who first introduced him to the notion of entropy. Robert Fano, (a colleague of Shannon’s from Bell Labs) stated that when he was a PhD student at MIT, Wiener would at times enter his office, puffing at a cigar, saying: “[y]ou know, information is entropy”[37]. What is a fact is that in 1948, Shannon published ‘A mathematical theory of communication’. It was a landmark paper, going further in the conceptual branching and opening a pathway which links entropy to information, explicating and generalising some of Boltzmann’s and Gibbs’ loose ends. Shannon’s theory states that the measure of information is entropy. This is equivalent to the average number of bits needed for communication. Information is inversely related to entropy. The entropy of a question is related to the probability assigned to all the possible answers to that question. It quantifies the uncertainty entailed when coming upon a random variable; Shannon-entropy entropy refers to the uncertainty associated with messages and can be linked to reduced Gibbs entropy –it is what we would today call “negative

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[36] Shannon interview by Robert Price, Winchester, Massachusetts, U.S.A., IEEE History Center, July 28, 1982. Partly published in Ellersick, F.W. (1984) A Conversation with Claude Shannon. *IEEE Communications Magazine*, 22. pp. 123–126.

[37] Robert Mario Fano interview by Arthur L. Norberg, Charles Babbage Institute, April 1989. Center for the History of Information Processing, University of Minnesota, Minneapolis. pp. 20-21.

entropy". It can be understood simply as the amount of Shannon-information needed to specify the microstate of the system, given its macroscopic description. The amount of Shannon information specifies the number of yes/no questions that would have to be answered to specify the microstate. Or, in the words of Gilbert Newton Lewis writing about chemical entropy, "Gain in entropy always means loss of information, and nothing more" (1930: 573). Shannon entropy (H)[38] is higher the *more random* the distribution is, or, strictly speaking, the closer the distribution is to a uniform distribution. Information is understood as deviation from a random stream of characters or numbers. The higher the information content is, the lower the entropy. Shannon understood that information resolves uncertainty, so the messages that resolve the highest amount of uncertainty convey the greatest amount of information. For example, the outcome of flipping a fair coin is more uncertain than the outcome of flipping a weighted coin, so the unfair coin stores more information. But, contrary to our ordinary daily use of the word "information", a string of random-looking text contains a higher degree of what is known as Algorithmic Information Content (AIC)[39] than a string of comprehensible text (which is structured by all sorts of rules and patterns that make it predictable). But if we take entropy to mean 'disorder', then the most disorderly-looking messages are the least information-rich in Shannon's terms. By contrast, more patterned messages are lower in entropy, and more information-rich in Shannon's terms. In Chapter 7 we will see how this apparent paradox is relevant to the issue of AIC.

Shannon's formula is widely used for the calculation of physical entropy. Physical entropy is a measure of the amount of randomness in a system. In the same way, a message with a high Shannon information content is one which is very random; it has been taken out from a large group of possible messages. It can work with Shannon's formula and is widely used for the calculation of physical entropy. Physical entropy is a measure of the amount of randomness in a system. In the same way, a message with a high Shannon information content is one which is very random; it has been taken out from a large group of possible messages. This randomness may amount, in its totality or in part, to useful information, or to absurdity. It can work with 'messages' such as art pieces or music compositions, the information content of which may be measured, though it will in no way amount to a measure of its relevance. Nor can Shannon's theory address the "deep and complex" (Ruelle 1991: 134) issue of meaning.

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[38] The entropy, H, of a discrete random variable X is a measure of the amount of uncertainty associated with the value of X (Shannon, 1948).

[39] We examine this in depth in chapter 7.

Shannon (1948: 379) states:

> The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently the messages have *meaning*; that is, they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem. The significant aspect is that the actual message is one *selected from a set* of possible messages. The system must be designed to operate for each possible selection, not just the one which will actually be chosen since this is unknown at the time of design

Information theory argues that information and thermodynamic entropy are opposites, since information introduces order and thus decreases a system's entropy . A maximally entropic signal, for instance, would be for information theory a "pure noise" signal, since we are more uncertain about the information content of the transmitted signal but, under that assumption, noise adds entropy to a system at the expense of increasing the difficulty of decoding it – more energy would be needed.

The idea of negative entropy, or negentropy was used in a wider scientific context soon after Shannon's introduction of his notions of information. Negentropy is so-called because it has as its premise the fundamental character of the second law of thermodynamics, which means entropy is ongoing and linked to irreversible processes. Negentropy occurs against the background of increasing, overall, entropy. Thus, life on Earth is negentropic, but it occurs against the background of an overall expenditure that results in increased entropy. The "negative entropy" notion that we are dealing with, is outlined in Schrödinger's book *What is Life?* as the following (1944: 25): "It is by avoiding the rapid decay into the inert state of 'equilibrium' that an organism appears so enigmatic … What an organism feeds upon is negative entropy". A system is recognized as having the capacity to not only avoid the effects of entropy production but also to do the opposite, to increase organization. Negative entropy is the source of order; it uses order to produce order.

Decades Later, the French physicist Léon Brillouin shortened the phrase coining the concept of *negentropy*[40], While citing Shannon as the architect of information theory, he clarifies:

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[40] Brillouin, L (1953) Negentropy Principle of Information. J. of Applied Physics, 24, 9. pp. 1152–1163.

> The origin of our modern ideas about entropy and information can be found in an old paper by Szilard, who did the pioneer work but was not well understood at the time. The connection between entropy and information was rediscovered by Shannon, but he defined entropy with a sign just opposite to that of the standard thermodynamical definition. Hence what Shannon calls entropy of information actually represents negentropy […] Information and physical entropy are of the same nature. Entropy is a measure of the lack of detailed information about a physical system. The greater is the information, the smaller will be the entropy. Information represents a negative term in the entropy of a system, and we have stated a negentropy principle of information. (Brillouin 1962: 161-293)

Brillouin's interpretation of Maxwell's Demon problem is that the demon's information enables him to organise molecules, thus decreasing the system's entropy; but this information had to be paid for by an increase in entropy elsewhere in the system. So, information and entropy are opposites and must have opposite signs; hence the idea of negentropy for information.

The notions of entropy, probability and randomness are so closely mathematically intertwined that the enactment of any one leads to formulation of the other two. In fact, the formula used by Boltzmann and Shannon had its roots in the eighteenth-century study of probability in games of chance by the French mathematician Abraham de Moivre as we can see in his *Doctrine of Chances*[41]. He proved a special case of the *Central Limit Theorem* a long time before Pierre-Simon Laplace rescued it from obscurity and hundreds of years earlier than Aleksandr Lyapunov and George Pólya developed definitions[42] and proofs[43].

Sir Francis Galton recounted the Central Limit Theorem in these terms:

> I know of scarcely anything so apt to impress the imagination as the wonderful form of cosmic order expressed by the "Law of Frequency of Error". The law I know of scarcely anything so apt to impress the imagination as the wonderful form of cosmic order expressed by the "Law of Frequency of Error". The law would have been personified by the Greeks and deified, if they had known of it. It reigns with serenity and in complete self-effacement, amidst the wildest confusion. The huger the mob, and the greater the apparent anarchy, the more perfect is its sway. It is the supreme law of Unreason. Whenever a large sample of chaotic elements are taken in hand and

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[41] De Moivre, A. (1756) *The doctrine of chances: or, a method for calculating the probabilities of events in play.* London: W. Pearson.

[42] See: Smirnov, V. I. (1992) Biography of A. M. Lyapunov. *International Journal of Control.* 55, 3. pp. 775–78

[43] Pólya, G. (1920) Über den zentralen Grenzwertsatz der Wahrscheinlichkeitsrechnung und das Momentenproblem. *Mathematische Zeitschrift.* 8, 3–4. pp. 171–181.

> marshalled in the order of their magnitude, an unsuspected and most beautiful form of regularity proves to have been latent all along. (1889: 66)

What is the probability distribution for the noise in an auditorium full of students chatting? This could be understood as an incongruous question, because the answer will depend on how crowded the space is, the differences in volume and tone of their speech and on what is being said in what language. The striking result from the Central Limit Theorem is that if there is a large number of people in the auditorium, then the distribution will approximately be Gaussian[44], independent of the details of what they say. That it is to say, there is going to be a *normal distribution*. It is often the case that when we measure some feature of a population (the weight of the chestnuts in your local forest, the velocity of cars in the motorway, etc.) the results cluster at some central value and spread out to the left and right in a bell-shaped curve. This is a way of describing the errors that arise when you average up sources of variation in the thing you are trying to measure. It is also called "standard deviation". Which is, of course, a very concrete measure of a system. An aspect of its order. Frequently, in the "real world", noise can be modelled as Gaussian because so many independent components are added together to produce a central-limit-theorem-type effect.

> if "mere chance" can so readily be confused with a causal structure, the effect of chance is itself entitled to be called a structure. The word "noise" may perhaps be reserved for the Gaussian error terms, or its binomial or Poisson kinds, which are seldom respected as sources of anything that looks interesting.
> (Mandelbrot, 1997: 94)

Information Theory tries to minimize the probability of errors caused by noise in a system using different *coding* techniques that best fit each situation. Shannon's paradigm (1948: 34), describes a source that generates an information message (i.e. a sequence of letters) addressed to a destination. The only connection between the source and the destination is a noisy channel which reproduces the signals that carry the information of its input message in a fallible way, thus a received message can be different from the transmitted one (an event understood as *error*) with non-zero chance. Error correction is used for controlling these

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[44] *Gaussian* or *Normal* distribution is a continuous probability distribution that has a bell-shaped probability density function (Gaussian function), commonly pictured as a bell curve. It was first described by De Moivre in 1733 and subsequently by the German mathematician C. F. Gauss (1777 - 1885). See: Stigler, S. (1986) *The history of statistics: the measurement of uncertainty before 1900*. Cambridge, Mass.: Belknap Press of Harvard University Press.

errors in data over unreliable or noisy communication channels[45]. Shannon's informational entropy is the number of binary digits required to encode a message. Nowadays, everything from a wireless router to a photograph stored in a smartphone rely on error-correction to function. In addition to formularised information, Shannon assessed the capacity to send information through a communications channel. He discovered that a channel had a certain maximum transmission rate that could not be exceeded. Today we understand this as the *bandwidth* of the channel –often called the "Shannon Limit". Shannon mathematically proved that even in a noisy channel with a low bandwidth, fundamentally flawless, error-free communication can be obtained by keeping the transmission rate within the channel's bandwidth and by using error-correcting code: the transmission of additional bits that would permit the data to be gathered from the noise-ridden signal. This is the "noisy-channel coding theorem". In a noisy channel, we try to achieve zero-error transmission by adding redundancy to the transmission. When the information contains redundancy, it is possible for us to reduce it to a more compact form. Let us suppose that we receive the sequence "0100011001", can we predict with certainty what the next couple of numbers are going to be? Quite likely not, it is very difficult, but if we receive the stream "0101010101" then it is not too hard to predict that the next two numbers are probably "01". And because we had a good idea that it would be "01", the confirmation that it is, in fact, "01" gives us very little information. This is a highly redundant data stream. The discovery of the theory is thus the discovery of redundancy in observed data and the reduction of its information into a smaller amount of data. Its predictive power is no more, in principle, than supposing another "01" is likely after a long stream of "01s". Without redundancy, our communications would have no defence against noise, but in a noise-free environment, we can code information so that it can be transmitted more efficiently.

In Shannon's probabilistic conception of information, the amount of information in a message may be interpreted as the length of a description of the message. This approach of encoding messages is based on the assumption that the messages to be encoded are outcomes of a known random source –it is only the properties of that random source that determine the encoding, not the properties of the messages that are its outcomes. Shannon's methodology is

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[45] See: Hamming, R. W. (1950) Error Detecting and Error Correcting Codes. *Bell System Technical Journal*. USA: AT&T. 29, 2. pp. 147–160.

interested in the minimum expected number of bits to transmit a message from a random source of known properties through an error-free channel.

1.8: Cybernetic Warfare

> Information is information, not matter or energy. No materialism which does not admit this can survive at the present day. (Wiener, 1948:132)

Independently of Claude Shannon, Wiener understood communications engineering as a class of statistical physics and applied this perspective to the concept of information. In 1948 he published at MIT *Cybernetics: Or Control and Communication in the Animal and the Machine*. While Shannon was looking for ways to optimise errorless message transmission, Wiener worked on research projects for the US military during World War II, attempting to develop his Anti-Aircraft Predictor (AA-Predictor), a machine that was supposed to anticipate the trajectory of enemy planes. Weiner saw the control systems used in these devices not as a series of interlocking mechanical processes, but rather as a continuous flow of information.

Norbert Wiener talks about the “Manichean Devil” as “[an enemy] who is determined on victory and will use any trick of craftiness or dissimulation to obtain victory” (1950: 34–35). In comparison with the Augustinian devil, the latter stands for the forces of nature, while the Manichean devil renders the enemy itself (just as the ‘enemy-unity’ of man and machine) and functions as a banner for the conceptualized enemy. This accentuates once again the deprivation of the enemy’s humanity during World War II. Wiener’s ambition was to employ radar to predict the upcoming position of aircraft, considering the most logical path (a straight line) and the turns the aircrafts were capable of, calculating anti-aircraft artillery trajectories. But measurement errors generated a positive feedback loop, amplifying the weapon’s motion and producing oscillations. Wiener needed a negative feedback loop to control its motion. He solved this by averaging the errors and feeding them back into the system –he did not just predict the most probable correct result, but also the most probable incorrect result, bringing together the tendencies in balance, or *homeostasis*.

He derived the concept cybernetics from the Ancient Greek word *kybernetes*, meaning *steersman* or *helmsman*. Interestingly used by Plato in the form of the “helmsman of the universe” (*Statesman* 273d; *Laws* 709b-c) i.e. the world-soul as the cosmos’ pilot; or with "reason" (*Laws* 961e). The etymology implies, then, not just the study of how information flows, but specifically how it is used to control systems, whether mechanical, biological, or social[46].

Both Shannon and Wiener had the need to formally characterise a fundamental unit of information, as essentially a yes/no choice, and both arrived at essentially the same formalism. Wiener’s third chapter on ‘Time series, information, and communication’ includes the first publication of his formula describing the probability density of continuous information. This was exceptionally close to Shannon's formula dealing with discrete time published in *A Mathematical Theory of Communication*. But Wiener’s interest in noise was particularly remarkable, an obsession with “finding predictability through chaos or signal through noise” (Heims, 1980: 184). He considered that the “highest destiny” of mathematics, the universal “language” of science, was “the discovery of order among disorder” (Heims, 1980: 68). Alfred North Whitehead claimed something very similar, in a much more poetic mode, when he stated that the quest of mathematics was “a divine madness of the human spirit, a refuge from the goading urgency of contingent happenings” (ibid.: 116). The detection and formulation of regularities brings greater predictability of phenomena and an improved control over the natural world. Auguste Comte, the founder of positivism, notably made this connection: “from science comes prevision; from prevision comes control” (King, 2000: 20). The scientific enterprise is therefore inseparably linked to the drive for greater control and power over the world –we only need to remember the notorious “scientia potentia est” by Francis Bacon.

For Wiener, the noise of disorganised structures and the entropic erosion of workable lines of demarcation between “subject-objects” in communicative flux were expressed in the swarming fluctuations in the radar receiver, the unpredictable deviations in flight paths. He understood that *noise’s mode of operation* was statistical, in the same way as Brownian motion, the extremely lively and wholly haphazard movement that van Leeuwenhoek had

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[46] Cybernetics influenced a whole generation of “functionalist” social science in the US. Most famously the sociologist Talcott Parsons.

observed through his microscope in the seventeenth century. Wiener had been studying and treating mathematically the Brownian motion in the 1920s[47]. The non sequitur behaviour fascinated him—not just the particle trajectories but the mathematical functions, too, seemed to go astray. This was, as he wrote, discrete chaos[48], a notion that would not be well understood for several decades.

In contrast to Shannon, Wiener understood entropy as "the equivalent of a cosmic pessimism – a universal Ragnarök or Judgment Day" (1950: 22) which his science of cybernetics was fighting against: "In control and communication we are always fighting nature's tendency to degrade the organised and to destroy the meaningful" (ibid.: 17) . It is from this point of view that cybernetics may be conceived as a reaction against the terror regarding the "heat death of the universe" at the end of the nineteenth century. If there is a "universal" inclination towards entropy and disorder, cybernetics could correct any random deviation from order by using information about the behaviour of the system in order to produce more regular behaviour, so that the system remains orderly. The general tendency towards increasing entropy remains but, on the background of this rising chaos and indeterminacy. Confusion, disorganisation, the noise that obscures it all is designated as "evil"[49], the diabolical archenemy of the scientist in search of the order governing the universe (ibid.). Bernard Stiegler (2015) makes the accurate remark[50] that, in fact, automated control and communication hastens entropy overall (since negentropic processes always take place against a constitutive background of overall increasing entropy) so negentropic emergence is now understood as, overall, a shortcut to equilibrium. Resistance to entropy by means of control is a chimera. Something else is required.

Wiener (along with Brillouin) performed a decisive change in sign to Shannon's equation. Information turned into the opposite of entropy –negative entropy or negentropy.

> The notion of the amount of information attaches itself very naturally to a classical notion in statistical mechanics: that of entropy. Just as the amount of information in a

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[47] It is interesting to know that Wiener was guided to the study of brownian motion by Bertrand Russell. Wiener had come to Cambridge with the plan of studying logic; Russell dissuaded him from doing this, and recommended him to read Einstein's 1905 paper instead.

[48] Wiener, N. and Wintner, A. (1943) The discrete chaos. *Am. J. Math*. 65, pp. 279-298.

[49] Wiener's view of evil here is that which St Augustine characterises as incompleteness (negative evil) rather than the malicious type of the Manicheans (positive evil). Wiener (1950), p.11 and pp.34-35.

[50] Thanks to Sean Watson for drawing my attention to this.

> system is a measure of its degree of organisation, so the entropy of a system is a measure of its degree of disorganisation; and the one is simply the negative of the other. (Wiener, 1948: 18)

Consequently, the objective of cybernetic systems led by information feedback (systems equipped with the capacity to regulate and alter future actions by past performance) is “to control the mechanical tendency towards organisation; in other words, to produce a temporary and local reversal of the normal direction of entropy” (Wiener, 1950: 24-25). Wiener and Brillouin understood entropy and information as opposites or regarded information as negative entropy because of the natural proclivity hypothesised by thermodynamics, for systems to evolve into states of greater disorder, i.e., states of increased entropy and consequently states for which we have less information. Think about a system that is in a state for which there is a certain limited number of potential configurations or microstates all of which are analogous to the same macro state. The direction of nature according to the second law of thermodynamics is for the number of microstates that are analogous to the macrostate of the system to increase. In view of the fact that there are more possible microstates as time increases and the particular microstate in which the system is, is unknown, we have a decreasing knowledge about the system as the number of probable microstates increases. Thus, as the entropy increases the amount of information we have about the system is reduced and hence entropy is negative information, or conversely information is the negative of entropy. Namely, the second law of thermodynamics reveals that when system X evolves into system Y, system Y will have more possible redundant or analogue micro states than system X and for this reason we have less knowledge about system Y than system X since the uncertainty as to which state the system is in has increased.

1.9: Algorithmic Information Theory: The Role of Randomness and Complexity.

It was during the 1960s when several scientists, Solomonoff, Kolmogorov, and Chaitin, gave rise to the notion of *Kolmogorov complexity* in their ground-breaking papers: “A Preliminary Report on a General Theory of Inductive Inference” (1960[51]), “Three Approaches to the

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[51] Solomonoff, R.J. (1960) A preliminary report on a general theory of inductive inference. (Revision of Report V-131). Technical Report ZTB-138, *Zator Co. and Air Force Office of Scientific Research*, Cambridge, Mass.

Quantitative Definition of Information” (1968[52]), and “On the Simplicity and Speed of Programs for Computing Infinite Sets of Natural Numbers” (1969[53]), respectively. Algorithmic complexity formalizes and quantifies the concepts of simplicity and complexity in an essentially unique way, but it is helpful for understanding the foundations of thermodynamics and its second law about entropy increase, for solving the apparent paradox of Maxwell’s demon,[54] and for being indispensable in order to effectively determine when something is random.

For Kolmogorov the primordial character of information is the *information content* of an object, without prompting into concerns about how this information is employed (as a message for example). This is a motionless conception of information. What Kolmogorov pursued is to provide a mathematical basis for the idea of randomness and to clearly express the concept of information content of a given object which is *intrinsic* to that object. As a result of this, he tried to find a mathematical theory of information which goes beyond Shannon’s in terms of abstraction, and finds its grounding in semantics and not only in the physical aspects of words and communication. As a solution, he proposed the consideration of computer programs (understood as computable descriptions, within the framework of calculability theory) which output an object and focus on the length of a smallest string (input, code) from which it can be reproduced by some computer (interpreter, decoder). In this way, taking into account both programs and what the program does, the *algorithmic information theory* founded by Solomonoff and Kolmogorov has both syntactic (length of a program) and semantic features (i.e. what the program does). In Chaitin’s words it is “the result of putting Shannon’s information theory and Turing's computability theory into a cocktail shaker and shaking vigorously” (2019).

In 1965 Kolmogorov, put forward the idea under which the complexity of a string of data can be defined by the length of the shortest binary program for computing the string. In this way, and following Shannon in the context of “redundancy”, the complexity of data is its minimal description length, and this determines the ultimate compressibility of data. The

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[52] Kolmogorov, A.N. (1968) Three approaches to the quantitative definition of information. *International Journal of Computer Mathematics*. 2, 1-4. pp. 157-168.

[53] Chaitin, G.J. (1969) On the Simplicity and Speed of Programs for Computing Infinite Sets of Natural Numbers. *J. ACM* 16, 3. pp. 407-422.

[54] See: Cottet, N., Jezouin, S., Bretheau, L., Campagne-Ibarcq, P., Ficheux, Q., Anders, J., Auffe`ves, A., Azouit, R., Rouchon, P., and Huard, B. (2017). Observing a quantum maxwell demon at work. *Proceedings of the National Academy of Sciences*, 114, 29. pp.7561–7564.

"Kolmogorov complexity" K of a string is approximately equal to its Shannon entropy H, thereby unifying the theory of descriptive complexity and information theory.
A primitive version of Kolmogorov complexity was published by Solomonoff (1960[55]; 1964[56]), as part of a theory of prediction. Solomonoff's main accomplishment was the characterization of an idealized method of prediction that uses this complexity measure to give greater probability to simpler extrapolations of past data: "Solomonoff Induction"[57]. In addition to this, he achieved formal proof of the reliability of this prediction method in terms of leading us to the truth in most cases[58]. Following Occam's razor, this is formalized as Minimum Description Length or Minimum Message Length, in which the total size of the theory is the length of the message required to describe the theory, plus the length of the message required to describe the evidence using the theory. This evokes Leibniz's 1685 *Discourse on Metaphysics*[59]. The short treatise addresses how we can differentiate between facts that can be outlined by some law and those that are lawless or irregular. Chaitin's reading of section VI of the *Discourse* suggests how Leibniz noticed that "a theory has to be simpler than the data it explains; otherwise it does not explain anything. The concept of a law becomes vacuous if arbitrarily high mathematical complexity is permitted, because then one can always construct a law no matter how random and patternless the data really are" (2007: 252)[60].

Kolmogorov-complexity allows us to seize an "objective" mathematical measure of the information content of an object[61]. Furthermore, this measure is in fact, intrinsically deep-rooted in the object (to a large extent, it is a *universal*[62] characterization of the information

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[55] Solomonoff, R.J. (1960) A preliminary report on a general theory of inductive inference. (Revision of Report V-131). Technical Report ZTB-138, *Zator Co. and Air Force Office of Scientific Research*, Cambridge, Mass.

[56] Solomonoff, R.J. (1964) A formal theory of inductive inference. Parts I and II. *Information and Control*, 7, 1–22. pp. 224–254.

[57] Solomonoff defined an inference system that will learn to correctly predict any computable sequence with only the absolute minimum amount of data. This system, in a certain sense, is the perfect universal prediction algorithm. He combined the Epicurean Principle and Occam's Razor in a probabilistic way according to Bayes Theorem, used Turing Machines to represent hypotheses and Algorithmic Information Theory to quantify their complexity. See for instance: McCall, J.J. (2004) Induction: From Kolmogorov and Solomonoff to De Finetti and Back to Kolmogorov. *Metroeconomica*, 55, 2-3. pp. 195-218.

[58] Solomonoff, R.J. (1978) Complexity-based induction systems: Comparisons and convergence theorems. *IEEE Transactions on Information Theory,* IT–24, 4. pp. 422–432.

[59] Leibniz, G.W.F. (1902) *Discourse on metaphysics*. Chicago: The Open Court.

[60] It is interesting to note that this is close to a description of the method advocated by Tom in *Structural Stability and Morphogenesis* (1972).

[61] We will examine this in much more detail in chapter 4, 5 and 7.

[62] Insofar as it is machine-independent up to (as mentioned) an additive constant and obtains an asymptotically universal and absolute character through Church's thesis, from the capacity of universal machines to simulate one another and execute any effective process.

content of the object) because is not dependent (up to a constant) on the determined programming language (a formal language comprising a set of instructions with the objective of implementing algorithms) to get programs (the list of instructions that can be executed by a computer): this is the content of "Kolmogorov's Invariance Theorem". Kolmogorov performs a severe abstraction from any physical apparatus which transmits information in order to arrive at the "absolute" mathematical notion of randomness. He develops the algorithmic information theory which enables the "computation" of the Kolmogorov complexity of any object. By the presentation of a conditional version of Kolmogorov complexity, he improves the idea of intrinsic complexity of an object by *relativizing it to a context* (we can understand this as an input for the program) bringing some extra information. This is the way in which Kolmogorov's fundamental contributions for the foundation "algorithmic information theory", can be understood as the mathematical foundation of the notion of randomness as well as the mathematical foundation of information classification and structuralisation.

1.10: Dynamical Systems and Order Through Noise

> Henri Atlan, has recently proposed an ingenious and complicated response to the question in the form of what he calls a "noise-based principle of order," according to which self-organizing systems evolve by taking advantage of "noise," or random perturbations in the environment. Might the meaning of organization lie in the ability to make use of dis-organization? (Canguilhem, 1994: 88)

One of the messages of the second law is that we are living in a world of *unstable dynamical processes*.

The foundations of the study of noise-induced processes can be traced back to the second half of the twentieth century. They proliferated particularly across the decades of the 1960s and the 1970s when previous self-organisation principles and developments, like the "principle of the self-organizing dynamic system" (1947)[63] by the cybernetician W. Ross Ashby, resulted in the formulation of a series of theories about the idea of noise generating order.

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[63] First published as Ashby, W. R. (1962) Principles of the self-organizing system, in *Principles of Self-Organization: Transactions of the University of Illinois Symposium*, H. Von Foerster and G. W. Zopf, Jr. (Eds.), Pergamon Press: London, UK. pp. 255-278.

The "order-from-noise principle", which was first proposed by Heinz von Foerster (1960)[64], establishes that noise or random perturbations will help a self-organising *dynamical* system to find more stable states in its adaptive landscape –a construct employed to describe the process of evolution of a system. "[S]elf-organizing systems do not only feed upon order, they will also find noise on the menu" (von Foerster, 1960: 43). In the adaptive landscape model, all attractors[65] are not equal: those with a higher adaptiveness are in a sense more favourable than the others. For self-organising systems, the notion of *more favourable* can be replaced with *more stable* or with *more potential for growth*: more potential for adaptive self-replication –individual, species etc. Nevertheless, the dynamics implicit by an adaptive landscape, commonly does not lead to the most adaptive position: the system has no option but to go by the way of the steepest descent. Usually, this way will end in a local minimum of the potential, not in the global minimum (figure 1). The only way to release the system out of a local minimum is to add a degree of indeterminism to the dynamics – that is, to enable the system to have the ability to make transitions to states other than the locally most adaptative one.

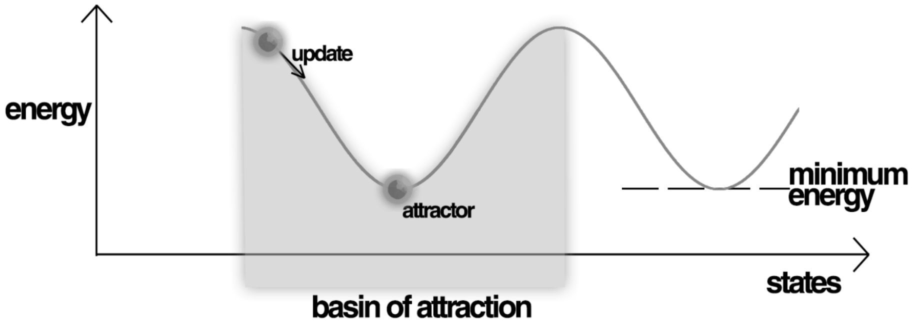

Figure 1[66]

This can be understood as the introduction of "noise" or random perturbations into the system, causing a deviation from its preferred trajectory. Physically, this is what commonly occurs with external perturbations. Such perturbations can drive the system towards a higher (in a relative sense, more adapted to prevailing conditions) potential . This may be enough to let the system escape from a local minimum, after which it will again start to descend towards

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[64] Von Foerster, H. (1960) On self-organizing systems and their environments. In M. C. Yovits & S. Cameron (Eds.), *Self-organizing systems*. London: Pergam.

[65] An attractor can be thought as the preferred position for the system. Any system that moves to a determined structure can be said to be drawn to an attractor. See: Milnor, J. (1985). On the concept of attractor. *Communications of Mathematical Physics*, 99, 2. pp. 177–195.

[66] Figure 1: Energy Landscape of a "Hopfield Network", highlighting the current state of the network (up the hill), an attractor state to which it will eventually converge, a minimum energy level and a basin of attraction shaded in grey. Diagram from Wikimedia commons.

a possibly deeper level. The more intense the noise, the greater the ability of the system to exit potentially deeper levels. This shows how all non-equilibrium processes are to some extent stochastic –the time evolution of a random variable.

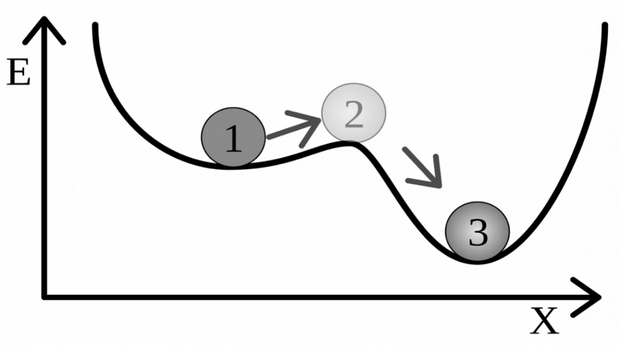

Figure 2[67]

Ilya Prigogine and Isabelle Stengers had to change the emphasis from closed systems –which are ultimately scientific idealisations– to opens systems, in order to corroborate the role of entropy in the emergence of complex matter. As was shown by the work of Kolmogorov and his colleagues, the theory of "unstable" dynamical systems provides a connection between dynamics and information theory. The central connection between system theory and probability theory/statistical mechanics is set by the Kolmogorov complexity *K* –also known as algorithmic entropy. Even though Prigogine and Stengers's 'complexity' refers to systems characterised by multiple variables interacting in a non-linear fashion –small changes in initial conditions leading to massive phase changes, bifurcations, transition between attractor states etc. Thanks to the measurement provided by *K*, we can classify the temporal evolution of dynamical systems as regular, chaotic, and stochastic processes. Given that *K* stands for the measurement of the internal information creation rate of dynamical systems, it proffers a way to address the issue of irreversibility. Dynamic systems arise from dissipative systems, systems which are thermodynamically open and operate out of, and often far from, thermodynamic equilibrium in environments with which they exchange energy and matter. "Prigogine's theory thus tallies to an extent with the results of Kolmogorov's complexity theory, demonstrating the central role of the conceptual evolution of coarse-graining technique in the development of the contemporary theory of complexity" (Carsetti, 2013: 15). The notion of "dissipative structures" was proposed in 1967[68] by Prigogine to describe the

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[67] Figure 2: Three positions of a ball on a surface to illustrate the concept of equilibrium. The "metastable" position (1) is a local low-energy well. Only the "stable position" (3) is the lowest possible energy configuration. Diagram from Wikimedia commons.

[68] Prigogine, I. (1967) Structure, Dissipation and Life, Communication at the *First International Conference: Physique Théorique et Biologie*. Amsterdam: Ed. Marois.

spontaneous appearance of ordered structures within non-equilibrium state of matter created by *irreversible* processes[69]. They aimed to give an account of the formation of (temporal, spatial and spatiotemporal) patterns in physico-chemical as well in biological and social systems. One of their primary objectives was to provide a mathematical basis of morphogenesis within biological organisms. Prigogine was awarded the Nobel Prize in Chemistry in 1977 for his pioneering work on these structures.

> "[N]oise", far from being a nuisance, produces new types of behaviour, which would imply, under deterministic fluxes, much more complex reaction schemes. It is important to remember that random noise in the fluxes may be considered as unavoidable in any "natural system." [...]. The sensitivity of nonequilibrium states, not only to fluctuations produced by their internal activity but also to those coming from their environment, suggests new perspectives for biological inquiry (Prigogine and Stengers, 1984: 166)

Linear thermodynamics makes sense of the un-fluctuating predictable behaviour of systems that tend towards the minimum level of activity possible. Nevertheless, when the thermodynamic forces acting on a system reach the point where the linear region is surpassed, stability can no longer be granted, perturbations arise. For a long time, perturbations were viewed as a negative alteration of a trajectory. But now, it has been exposed (Prigogine, 1996) that what seems to be merely 'chaotic disorder' on the macroscopic level, it is, in fact, highly organised on the microscopic level.

It was mechanics that needed to be altered, or its formulation outstretched, to become reconciled with the reality of irreversible processes and the arrow of time. Accordingly, Prigogine advocated the elaboration of the theory of non-unitary transformation. In his 1977 Nobel Lecture, he stated in his concluding remarks:

> The inclusion of thermodynamic irreversibility through a non-unitary transformation theory leads to a deep alteration of the structure of dynamics. We are led from groups to semigroups, from trajectories to processes. This evolution is in line with some of the main changes in our description of the physical world during this century. (Prigogine, 1978: 785)

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[69] Prigogine and Stengers' concept of "dissipative structures" also finds its "onto-scientific and onto-genetic relay in Simondon's non-hylomorphic materiality" (Atamer, 2011).

1.11: Groupe des Dix

In the aftermath of May 68, the group was formed in 1969 with an evident interdisciplinary vocation of applying cybernetic concepts to society and politics[70]. Groupe des Dix attempted to envision a new society in which science would be an instrument to resolve social crises and guarantee successful social management. Von Foerster's "order-from-noise principle" features prominently in the work of some of the key members of the "Groupe des Dix"[71]: Henri Atlan, Edgar Morin, Jacques Attali and Michel Serres. By the time the group disbanded in 1976, they clearly paved the ground for a significantly fertile theoretical framework of noise. I will address briefly here some of the main examples and their implications.

Henri Atlan in *Noise as a Principle of Self-Organization* (1972)[72] states that living organisms not only resist noise effectively but that they also have the ability to utilise it, transforming noise into a factor of organisation. The misidentification of noise with disorder and randomness which produce "errors" in the system, is perfectly addressed by Atlan:

> The noise provoked in the system by random factors in the environment will no longer be truly noise from the moment it is used by the system as a factor of organization. This is to say that factors in the environment are not random [...] from the moment the system is capable of integrating these errors into its own organization— then these errors lose, a posteriori, a little of their character of error. (Atlan, 2011: 111)

This potentially productive role establishes a distinction between systemic levels. In the context of information, Atlan noticed that Shannon's articulation of ambiguity in a channel

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[70] Very much in line with the ten legendary "Macy Conferences" in New York between 1946 and 1953 with participants drawn from engineering, biology (particularly fields dealing with neural systems), medicine, and the social sciences (most particularly psychology), or the Ratio Club in the UK between 1949 and 1958 –which comprised young psychiatrists, psychologists, physiologists, mathematicians and engineers. See: Pias, C. (Ed.). (2003) *Cybernetics – Kybernetik. The Macy-Conferences 1946-1953.* Zürich/Berlin: diaphanes.; Husbands, P. and Holland, O. (2008), The Ratio Club: A Hub of British Cybernetics. In Husbands, P.; Wheeler, M. and Holland, O. (Eds.), *The mechanical mind in history*, Cambridge, Mass.: MIT Press.

[71] Some of the members of the group were: Henri Atlan, Jacques Attali, Jean-François Boissel, Robert Buron, Joël de Rosnay, Henri Laborit, André Leroi-Gourhan, Edgar Morin, René Passet, Michel Rocard, Jacques Robin, Jacques Sauvan, Jack Baillet, Alain Laurent and Michel Serres. See: Chamak, B. (1997) *Le Groupe des Dix ou les avatars des rapports entre science et politique*. Paris: Editions du Rocher.

[72] Henri Atlan, "Noise as a Principle of Self-Organization" in Atlan, H. (2011). pp. 95–113.

(i.e., equivocation) “has two different meanings according to whether one is interested in the information transmitted in the channel or in the information transmitted to the observer from a whole system in which the channel is part of a redundant communication network” (Atlan, 1974: 295). We find the same idea in Gregory Bateson’s work. In his formulation: “All that is not information, not redundancy, not form and not restraints —is noise, the only possible source of new patterns” (Bateson, 2000: 140). This distinction allowed Atlan to differentiate between the two opposed effects of noise on the information content of a system or an organism, in particular, between the two sides of ambiguity (equivocation): ‘destructive’ and ‘autonomy-producing’ resulting (respectively) in decreasing and increasing information content.

Atlan cultivates this conception by accentuating how noise in a channel might not always reduce, but improve the information value of a particular signal. In his definition there is the idea of noise as a *vector* of variety and heterogeneity in a system. He also reported that the consequences of noise on the information content can under certain conditions result in a higher complexity of information at a different level of organisation (Atlan, 1974). In his approach of complexity-from-noise, loss of information at one level in a hierarchical system is attested to be an achievement of information at a higher level (ibid.). What, at the level where the translation takes place, appears as a loss of information due to noise might entail positive results at other levels of the organization in accordance with a complexity-from-noise principle (Atlan, 1981). From a position higher up in a hierarchy an observer can perceive both the initial message and the state in which it was received after a transmission process. The fact that a message did not reach a receiver due to noise in the channel may in itself constitute valuable information.

Edgar Morin, intended to reinforce the idea under which; all that is unpredictable and contingent in the operation of systems: “[t]he ambiguities, uncertainties, and ‘noise’ of the environment pose questions, problems, puzzles, charades to living beings who, in response, develop communicative networks that weave together in the ecosystem and thereby contribute to the enrichment of ecocommunication.” (1980: 39). It is interesting to note how in *Le Paradigme perdu: la nature humaine* (1973) –the prolegomenon to a multi-volume work, *La méthode* (1992)– characterises the evolution of Homo sapiens by a massive increase in disorder as well as a psychological and affective outbreak of violence: “La violence, circonscrite chez les animaux à la défense et à la prédation alimentaire, se déchaîne chezl'homme, hors du besoin" (1973: 122). For him, social complexity draws attention to the widespread presence of noise in the form of uncertainty and struggle –in primate social networks that must have predated human societies from the point of view of evolution (1973: 37). These primate societies provide evidence of the "brownian motion", or noise, of the deficient inclusion of individuals and pervasive confrontation that offers a kind of "metabolic richness" (1973: 45-46). According to this, Morin implies that it is not just biological inheritance that primates passed on to humans, but also includes crucial cultural heritage. Error, simply put, is for Morin part of human nature (1973: 120) and as we know, constitutive of the evolution of all life on Earth.

Atlan acknowledges the efforts of mapping the frontiers of a new paradigm of complexity in *Paradigme perdu*, but maintains that Morin has an inclination towards the positive productive potencies of disorder, and for this reason overlooks the relevance of creating methods of reproduction and repetition. He draws attention precisely to Morin's "fascination" with "human error" (1979: 212). Atlan identifies in this regard, the efflux of the radical political movements of the late 1960s and early 1970s (1979: 200-201). Later on, Morin addressed Atlan's criticism by clarifying, and augmenting the formulation of his own particular reading and analysis of the order from noise in the first two books of *La Méthode* (1992): "for the observer, noise is ignorance psychically (and thereby unknown, mysterious) and disorder physically; for the observer, redundancy is certainty psychically and order physically" (1992: 360). Knowledge (for Morin) increases by means of the "redistribution of redundancy, of information, of noise" (ibid.) but, as a consequence of the laws discovered by Brillouin, "an exhaustive observation [would] necessitate infinite information, which [would] necessitate infinite energy" (ibid.: 362).

In 1977, Jacques Attali published *Noise: The Political Economy of Music*. In this work, he highlights that: far from being a strictly negative event, the flooding of information with noise is capable of constituting new levels of information complexity, new forms of political, social, economic, or artistic organization. He emphasizes the relevance of this method of approaching noise, as the driving force of a vast plurality of crisis out of which novel forms of organization of increased complexity emerge. The idea that noise might not only be refractory but also a creative power enables *Noise: The Political Economy of Music* to offer an interpretative template for grand scale historical changes.

Attali identifies different roles, under which noise can be explained: as an index of life (1984: 3) as originary chaos, (ibid.:6) as unformed energy, (ibid.:25) as violence. (ibid.:26) as catalyst (ibid.:34) as catastrophe (ibid.:33), etc. All share the common ground of "creation of order out of noise" responsible for the sequential rhythm of destruction and reconstruction that pushes through the transition between the four historical regimes identified by Attali in his book: from sacrifice, via representation and repetition, to the decisive idealistic regime of composition. It is very interesting to now re-read his diagnosis in light of the election of Francois Mitterrand 1981 as President of the French Republic in 1981, and how Jacques Attali took the role of special advisor to the President of the Republic from 1981 to 1991. It was in this context that Atlan presented the proposal for the creation of CESTA (Centre d'études des systèmes et des technologies avancées). Motivated by the gatherings and discussions held by Groupe des Dix and conscious of the priority position that the computing revolution should have in the political agenda, Attali requested the foundation of a centre for forecasting and facilitating decision-making. This eventually led to the creation of a European technological cooperation project, EUREKA (E!) in 1985. Since then, he continued to provide economic advice to the French presidency: Nicolas Sarkozy nominated him the head of the Commission to promote French Growth, François Hollande requested him a report on the concept of positive economy, Atalli even claims the invention of Macron: "Emmanuel Macron? I discovered him; I *invented* him" (2017: 117). Gilles Châtelet, who described Attali as "one of the most zealous acrobat-intellectuals of the future global neurocracy" (2014: 115), brilliantly, points out the dark and disturbing political reverberations of how Attali's program:

> [a]im[s] to *mask a crucial dissymmetry* in the givens of a problem...in order to stage the Miracle of auto-emergence...Dissymmetry is given from the start, which vitiates the theses of the "Gardeners of Chaos" who would see in such examples a "refutation" of Boltzmann's principle of increasing entropy" (2014: 121)

At the intersection between literature and science, Michel Serres developed the concept of 'the parasite' (1980) sharing Atlan's view of positive equivocation (as a stimulus for increased organization) as well as Shannon's understanding of *enemies* and noise. He first introduced this notion in the early volumes of his series *Hermès* (1982) and obtained notoriety for the account he provides in *Le parasite* (1980). In his work we can see how the "enemy cryptanalyst" (Shannon, 1949: 657), just like noise, is both parasite on (relating to a relation), and paradox of communication systems. For Serres, they are configured against a background of chaotic noise and violence. They take shape in the conflicts of different classes and circles to defend their own conceptions of truth, trying to receive social acknowledgement (from their contractual protocols) for conquering it. Serres tried to establish the grounds of a general theory of communication that 'privileges' noise over information. In order to do this, he introduced the idea of a "third player" [73] in the arrangement of a dialogue. He states that: "to hold a dialogue is to suppose a third man and to seek to exclude him; a successful communication is the exclusion of the third man […] We might call this third man the *demon*, the prosopopeia of noise." (1968: 41). Serres conceives his idea of a third man (the parasite[74]: the unwelcome guest) through the law of excluded middle of Boolean logic. Following mathematics, we can exclude a third possibility between true and false, according to that, we can see dialogues unfolding from the exclusion of a third man who jeopardizes effective communication. He reintroduces this player into the language game, deconstructing the due order that qualifies information over noise. The way in which he operates the third man in different application fields (from thermodynamics to communication systems, economics etc…) is extensively promiscuous. Since its originary transposition from information theory, Serres takes advantage of the scientific miss-unifications of noise and thanks to these liminal equivocations, his theory of the parasite emerges as a sort of universal screening element, with the capacity to assess the distinctions between different types of exchanges. The parasite is any 'disruption' of a relation: whatever diverts the accomplishment of an objective, for good or for bad, and whatever disrupts a third, regardless its magnitude. As Serres states, "The parasite brings us into the vicinity of the simplest and most general operator on the variable of systems. It makes them fluctuate by their differential distances" (1980: 191). For him, what qualifies channel and parasite, or information and noise, or relation and relation to relation, is a function of position or point of view. This could be understood as Mary Douglas's (1966) well known image: just as dirt is matter out of place, we may say that *noise is information out of place*, present as well in Gregory Bateson's (2000) reformulation of Shannon. We can see how the parasite is really a joker, who takes on different values depending on its position in a system. The problem is how Serres' own rhetoric of noise *itself parasites* the generalization of scientific models of noise. His parasite can be, by his own definition, everything. Jack of all trades: noise or

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[73] It might be argued that the notion is a deviation from Peirce's notion of thirdness. See: The Principles of Phenomenology. In: Buchler, J. (Ed.) (1955) *Philosophical Writings of Peirce*. New York: Dover Publications. pp. 74–97.

[74] In French, *bruit parasite* is static or interference.

signal, enemy and friend, code or channel, edge or node etc. His metaphor remains uninstructive.

1.12: Conclusion

Despite the fact that it is clearly connected to entropy, *information* is neither equivalent with it, nor its contrary. Information involves both pattern and order, as well as randomness and disorder. Noise and information are not steady and/or uniform notions, nor independent to the frame of reference in which they operate. This opposes Shannon information which is independent of organisation, meaning and its material instantiation. In this chapter we have shown how information is relative insofar as it is not a “all-encompassing” concept across the different disciplines. Information as a form of organisation for either culture or language, cannot be linked to Shannon information since cultural and linguistic information are meaningful and context-dependent, diverting significantly from the model for communication that Shannon described in his noisy-channel coding theorem. Culture and language evolve and change in unpredictable ways, ways that Shannon information cannot adequately describe. The meaning of a sentence never remains the same, as its meaning changes ever so slightly, every single time it is employed, insofar as the context in which it is uttered is constantly changing. It is not useful to understand information as the reduction of uncertainty, since irrespective of how much we have learned from the information of a particular system, uncertainty remains unlimited because the amount of different possibilities for the evolution of such a system are endless.

Although it could be helpful in certain contexts, the use of negentropy for information also has some clear limits in its application. Essentially, –as Blum (1968) pointed out– negentropy is a probabilistic notion, corresponding to an increase in order, and in connection with pattern and arrangement. But we need to stress that it is merely the opposite of thermodynamic entropy, and does not concern *meaning* in any way. In fact, it has been demonstrated (Wilson, 1968) that Brillouin’s proofs of scientific concepts in information theoretic terms function just as well if the signs are inverted. Ben-Naim (2008) sees the analogy between “negentropy” and information as “corruption” (2008: 141), he considers that it would be more appropriate to call entropy neg-information. Wicken (1987) also claimed that Brillouin was not able to distinguish information and order in an appropriate way, the latter being better understood in terms of negentropy.

I agree with Ben-Naim when he emphasizes the problems that the interpretation of "entropy *as* disorder" faces after more than 100 years of its continuous application (2008, 2009, 2011), namely: the fact that there are instances where disorder is unequivocally perceived without a corresponding energy change, and, more importantly, that the notion of order is not clearly established, so that it is hard (if not unfeasible) to identify which of two states exhibits more or less order. The notion of disorder is "at best a vague, qualitative and highly subjective one" (Ben-Naim, 2008: 10). He favours an interpretation of entropy in terms of Shannon's measure. Precisely for this reason, Ben-Naim, Ford (2013) or ourselves, maintain that *entropy* –in all contexts in which the term is employed (not just circumscribed to thermodynamics)– should be better understood in terms of *uncertainty* or *missing information* rather than *disorder*. Given the fact that we do not have access to all the information of a complex system, *entropy* stands for that *missing information*:

> Entropy is uncertainty commodified [...] We do not or cannot measure all the details of the present state of the world and so when processes occur we are not quite sure what will happen [...] Our certainty about the future is less than our certainty about the present [...] The increased uncertainty is quantified as an increase in the total entropy of the world, and that is what entropy is. The most remarkable thing is that we can measure it with a thermometer.
> (Ford, 2013: xiii)

Time advances, our picture contains an increased amount of 'missing information', entropy increases, uncertainty increases. This does not contradict Wiener's understanding of entropy, insofar as both Shannon and Wiener agree that entropy relates to uncertainty. Hayles specifies:

> Shannon considers the uncertainty in the message at its source, whereas [Wiener] considers it at the destination. To ask which is correct is like asking whether a glass is half empty or half full. The answer is important not because it is correct but because it reveals an orientation towards the glass and, by implication, an attitude towards life. Similarly, the [two] heuristics reveal different attitudes towards chaos by their orientations toward the message. (1990: 558–559)

Shannon poses that the more 'certain' a message is, the less information it contains; Wiener, on the contrary, finds that the more 'surprising' a message results, the less information it conveys.

After all we have just seen in the present chapter, we arrive in a period that might be understood as the "contemporary history" of noise studies. The next chapter will address the very constitution of randomness and its interdependencies with noise, while in chapter 3 I will present (via Simondon) a contrasting conception of noise as a negentropic (never-ceasing, never-ending) condition of morphogenesis. From chapter 4 onwards, I will examine the influence of noise in some of the philosophical (extended mind thesis [chapter 5]), scientific (synthetic biology [chapter 6]) and technological (algorithmic regimes of knowledge production [chapter 4 and 7]) developments that characterized this present moment in time.

Chapter 2: The Riddle of the Sphinx

> Such is our guess of the secret of the sphynx. To raise it from the rank of philosophical speculation to that of a scientific hypothesis, we must show that consequences can be deduced from it with more or less probability which can be compared with observation. We must show that there is some method of deducing the characters of the laws which could result in this way by the action of habit-taking on purely fortuitous occurrences, and a method of ascertaining whether such characters belong to the actual laws of nature. The existence of things consists in their regular behavior […] Not only substances, but events, too, are constituted by regularities. The flow of time, for example, in itself is a regularity. The original chaos, therefore, where there was no regularity, was in effect a state of mere indeterminacy, in which nothing existed or really happened. (W 6: 208-209)

2.1: Introduction to the Chapter

There is a question that some might say *needs to be asked*, others will be surprised *it has not been asked enough already*. The question is as 'simple' as: what is randomness and where does it come from?

Noise and randomness have always been entwined concepts – as we have seen, Shannon's definition of information is that the measure of information is one of randomness and unpredictability. Randomness, probability and noise have been developed together in the natural sciences since the time of at least Lucretius –and so any philosophical exploration of noise must also encounter randomness. Randomness is part of the history of noise, since noise is randomness, is interference, is fluctuation.

This is eerie territory to venture into. Everyday thinking takes the randomness in our life as a form of givenness[75]. We offset for that randomness with probability theory. Nonetheless, is randomness even 'real' or is it just a by-product of the limitations of our faculties of understanding and reason? Namely: is what we account for randomness just a 'representative' of our uncertainty about reality? Or is it evidence of something else?

Some of these questions were already raised in the previous chapter (and they will continue accompanying us throughout this thesis), but in this chapter we will look more closely at our understanding (and historical evolution) of randomness and, ultimately, probability as they figure in the history of the concept of noise. I will present a consistent examination of the available theses concerning randomness and its central problem regarding the difference between ontic/ontological and epistemic randomness. This being so, the argument presented here will emphasize the philosophical relevance of the former over the latter.

Randomness is typically put together with order, determinism, prophecy, and future. One of the leading ethos of Enlightenment was to eradicate anything unpredictable as flying in the face of God's design (Paley, 1881), *ergo* atheistic. The Swiss mathematician and an early proponent of Leibnizian calculus Jakob Bernoulli stated: "Everything that exists or originates under the sun, – the past, the present, or the future, – always has in itself and objectively the highest extent of certainty" (1713: 8). In 1718, French mathematician De Moivre argued that we could interpret all phenomena in terms of how likely it would be for them to occur, *i.e.*,

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[75] My use of this term is conceptual and deliberate, and we will return to this towards the end of the chapter.

degree of certainty, or probability. In consonance with most of the natural philosophers of the time, he did not consider chance as something ‘real’; everything was *ordered* (De Moivre, 1756: 253). Einstein famously asserted about uncertainty (randomness) that God is not “playing at dice” (Born, 1971: 91) pointing to the fact that the quantum mechanical equations themselves are deterministic even though they look probabilistic. Bertrand Russell was himself hesitant to renounce rigorous determinism, affirming that “Where determinism fails, science fails” (Russell, 1996: 67). As it was anticipated in the first chapter, according to Rene Thom, chance is “an empty concept”, a “secular substitute of divine finality” (1983: 19-12). The idea persists until our own days: “‘[T]rue randomness’ is a mathematical impossibility” (Fiorini, 2014: 2). Calude (2017: 172) goes further stating: “There is no true randomness, irrespective of the method used to produce it”. Since everything is rigidly physically determined, there is always the underlying pattern of physical determination lying behind the apparent randomness. From this point of view,‘real’ unpredictability would have to be based on physical principles, or a kind of logical notion of randomness that would involve ‘radical’ lack of structure. Two physically identical dice throws with two different results: is the main hypothetical scenario that serves as an illustration for the denial of ‘true’ randomness. We should be able to repeat this identical dice throw and the permutation of the set of results will remain *patternless* if real randomness exists. Underlying patterns of physical determination ensure that this is not the case however.

We can understand therefore, von Neumann words:

> Anyone who considers arithmetical methods of producing random digits is, of course, in a state of sin. […] There is no such thing as a random number - there are only methods to produce random numbers, and a strict arithmetic procedure of course is not such a method. (1951: 36)

A mathematical procedure is, itself, deterministic - so a mathematically generated ‘random number’ is, by his definition, not ‘random’.

Our survival skills as human species depend on recalling patterns of previous events in order to adapt to the changing environment by reducing uncertainty. But humans also lean on uncertainty (encryption and defeating bias). Tables of random numbers are formed on the basic presupposition that we (as humans) subconsciously create patterns but cannot generate randomness.

This demands close examination of the notions frequently used in conjunction with "random", such as "probability", "chance", "correlation", and "uncertainty".

2.1.1: Randomness and Probability

The problems in the understanding of the notion of probability never stopped its flourishing and favourable employment in a wide range of disciplines. This is due to the fact that probability calculus is a highly effective methodology for computing, from given probabilities, other probabilities that are predicted on the previous ones in a more or less complex way. Thus, within the calculus of probabilities the meaning of probability does not matter, insofar as the meaning of the prior and posterior probabilities stays the same. In Poincaré's words: "Every probability problem involves two levels of study: the first—metaphysical, so to speak—justifies this or that convention; the second applies the rule of calculus to these conventions" (Byrne, 1968: 329). We could say that some metaphysical theses are the conventions we adopt as required to generate logical truths. Probability and randomness share the processes by which we unbiasedly selected from an "infinite" population (Ramsey, 1931). However, we must not confuse one notion with the other. Basically, if we are not able to predict the nature of the next event, then, we consider that event 'more random'. Statistician Soubhik Chakraborty argues that "there should be four motivating factors for calling a phenomenon random: ontic, epistemic, pseudo and telescopic, the first two depicting 'genuine' randomness and the last two 'false'" (2010: 1). He repeatedly stresses the importance of understanding randomness before addressing probability, Chakraborty distinguishes two types of "genuine" (ibid.) randomness: ontic and epistemic randomness. He defines those adjectives in the abstract as:

> *Ontic*: What is actual (irrespective of what we know).
>
> *Epistemic*: What we know (hence it relates to our knowledge of something).

Here, when Chakraborty mentions "something" of which we have knowledge, and *is* actual, it entails both epistemic realism and ontic realism. This means that all knowledge-items are equally real: formulae, algorithms, numbers, laws, protons, etc. Both ontic and epistemic randomness imply epistemic probability. Statistical techniques enhance predictability and reduce randomness, on the assumption that the future resembles the past (Whewell, 1847; Hume; 1888; Keynes, 1921: 305-314). Divergence from the expected values in a probability analysis is understood as an instantiation of randomness. If this observation does not assist in conducting the prediction, the event is said to be "random" (Eagle, 2005).

The "axiomatic system for probability" on which Kolmogorov worked in the early 1930s put probability in its "natural place, among the general notions of modern mathematics" (Kolmogorov, 1933, v). Therefore, Kolmogorov provided a mathematical definition (in terms of sets) of what is entailed by a "random event". Up to this point, the basic concepts of probability theory had been "considered to be quite peculiar" (ibid.). His purpose was to establish contemporary probability theory, firmly based on set theory. Thanks to his work, probability theory is as well-grounded and respected as any other area of mathematics (Kallenberg, 2002). Despite this, in contrast to a large number of other branches of mathematics, there is no general agreement about where to track down probability in 'real-world' scenarios. Within the two ruling branches of probability theory, "frequentists" address probability as long-run stable frequencies of events, and "Bayesians" address probability as a measure of subjective degree of belief. Again, in broad terms, we can distinguish between two distinct interpretations of probability: "epistemic" and "physical probability" (paralleling the distinction between epistemic and ontological randomness). The former would be what Carnap (1945) identified as his "probability$_1$", today understood either (following Carnap himself) in terms of evidential probability, or as credence or degree of belief. This differs from the latter interpretation that would be what Carnap's calls "probability$_2$", which entails a notion of a non-epistemic objective kind of probability, also known as *chance*. The physical interpretation understands probability as an actual attribute of physical systems such as: mass, energy and momentum.

Given these discrepant claims, this chapter has several objectives. First, to distinguish between the different interpretations of randomness and probability and to provide a general view of *noise's incertae sedis*. Philosophy of science provided numerous explanations for what actually grounds chance and a recapitulation of these explanations is needed. Second, I will make a case in favour of the philosophical legitimacy of the, above mentioned, distinction between "ontological" and "epistemic randomness,". This distinction has been ridiculed and denounced as irrelevant in the 'real world' (Taleb, 2010). In order to do so, I will cover briefly some ground principles concerning the epistemic approach with respect to randomness and probability, and I will focus in more detail on the ontological (physical) interpretation of probability. Finally, I will address the implications of an ontic understanding of randomness for a deterministic view of physical systems. Taking the ontological route is an obligation of principle since *noise exists.* Noise presents an objective ontological condition, but not, as Wilkins argues (2015: 24) "*only* as an effect of information processing dynamics and multi-scale complexity"; but precisely on the contrary: *as a co-constitutive condition* (as we will see in chapter 3) of information processing dynamics and multi-scale complexity.

2.2: Applied Demonology 2: Laplacian Origins

Six years after 'Stop Chance! Silence Noise!' (1983), Thom streamlined his trajectory with another short paper entitled 'Postface au débat sur le déterminisme' (1990). In this text, Thom agrees with Amsterdamski's distinction between 'local' and 'global' determinism (Amsterdamski, 1990). He acknowledges the fact that it is impossible to agree on a global determinism. This is due to the fact that the object of scientific research is invariably limited and consequently the determinism that we are able to 'extract' from it is unavoidably 'incomplete': *local*. These meditations led Thom to a gradual redevelopment of his initial arguments and (in the end) to advocate for a species of epistemological determinism. Within this, a deterministic assumption continues on the basis of the ethics of science and does not posit a conflict with the ontological status of reality as such. In other words, Thom maintains that reality must be deterministically conceived if reality is to be 'completely knowable' reality –even though such a knowledge will never be de facto completed:

> Perhaps the metaphysical choice for global determinism is not particularly interesting for science [...] In the never-ending adventure of scientific research, one has of course to stop [...] but such stops are due to the failures of our intelligence rather than to an 'essential' impossibility to go beyond. (Thom, 1990: 277–278)

His assertions regarding a merely "local" determinism (which we can characterise as 'epistemological' in contrast to ontological and/or metaphysical depictions) still seem incompatible with two of his own sentences in the essay: "I am among those who do not believe that God plays dice" (ibid: 275) –in clear reference to Einstein's pleasantry– and "the conflict determinism/chance is the manifestation of an ontological preference either for the substance or for the attribute' (ibid: 275, 279 note iv). In view of Einstein's statement, this latter passage acquires the surprising status of an ontological standpoint. Actually, when Thom connects substance with determinism contra attributes and chance, he renews his fire on "the deconstructors of being, the detractors of order and cantors of chaos", which actually "prefer statistics to determinism" (ibid: 279). This is a highly informative phrase as regards stipulating the connection between probability and uncertainty. Thom here, states again strongly, an ethico-ontological decision for "substance" and "cause" as the main instruments of determinism in opposition to the "popular epistemology" which would overturn being into trivial relations thus "outrageously glorifying chance" (Thom, 1983: 61).

Under this approach, substantialism and determinism are completely intertwined, within a sort of 'impromptu' philosophy for scientists which heads back to a notable old creed propounded by the Aristotelian-Thomist tradition. In the negative space of any determinist and substantialist epistemology we tend to perceive a basic Cartesian-like metaphysical dualism. Because of its Cartesian descent, this inclination towards determinism appears to preserve a metaphysical dualism which no phenomenological reduction can overcome. Both (neo)Kantian epistemologies and empiriocriticism[76] remain within the standpoint of a science envisioning reality as a totalised complete system under the disenchanted scrutiny of the subject. We find a clear manifestation of this in the repercussions of Laplace's Demon. As highlighted by Thom in his preface to the 5th edition of *Essai philosophique sur les probabilités* (1986), despite the fact that Laplace rejected any natural and therefore uniform constitution of the subject, he could do nothing but construct (in the same manner as Descartes did) a metaphysical hypostasis on which he could establish the hypothesis of the exteriority of the subject's view according to its object-universe (Thom, 1986: 22–23)[77]. It should be mentioned that, in contending this same critique of Laplace, as a matter of fact, Thom sees himself as part of the lineage whereby the 'capricious' organization of the subject of science relies on an 'ontological difference' between nature and humans: "in order to assume epistemic significance, determinism necessarily requires human free will" (Thom, 1990: 272)[78]. A professed ontological difference unmasks itself here on the basis of the

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[76] Understood under Richard Avenarius' theory of knowledge, according to which the major task of philosophy is to develop a "natural concept of the world" based on "pure experience". See his *Der menschliche Weltbegriff* (1912) Leipzig: Reisland.

[77] Arguably it is not just the various forms of phenomenological evasion, and empiricist naivety that are guilty of this, but the entirety of "subject blind" mechanical materialist scientific ontology.

[78] There is no doubt that mechanical materialism and Enlightenment humanism directly imply one another. One of the reasons that the second followed so rapidly from the first.

assumption of an anthropological difference, an elementary epistemological 'significance' firmly settled in an alleged 'human nature', which would reveal itself in the continuous disposition pointing to the inquiry of truth:

> All these efforts in the search for truth tend to lead it [l'esprit humain] back continually to the vast intelligence which we have just mentioned, but from which it will always remain infinitely removed. This tendency, peculiar to the human race, is that which renders it superior to animals; and their progress in this respect distinguishes nations and ages and constitutes their true glory. (Laplace, 1814: 3–4)

Thom's subjectivism argues not that indeterminacy does not exist but that it is not consistently thinkable and, by virtue of how we interact with the world, not sensibly demonstrable.

According to Laplace's work, the Solar System's past and future could be calculated and the accuracy of this prediction, rest on the ability to know the initial conditions of the system, a really difficult demand for "geometricians," as pointed out by d'Holbach and Le Verrier[79]. Henri Poincaré devised an alternative perspective[80], so as to take a close look at the evolution of a physical system over time, we have to build a model grounded on a choice of laws of physics and to enumerate the required and adequate variables that define the system – differential equations are always in the model, since one is calculating multiple relative rates of change and their outcomes. We can characterise the state of the system at a certain point in time, and the set of these system states is known as "phase space". What we understand by "sensitivity to initial (contour) conditions" was identified by Poincaré in his research of the "*n*-body problem"[81]. Later on, Jacques Hadamard employed a mathematical model known as "geodesic flow"[82] on a surface with a nonpositive curvature, named "Hadamard's (dynamical) billiards"[83]. The trajectories of frictionless particles on a billiard table with a concave wall diverge exponentially from one another, which is typical of chaotic motion.

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[79] See: D' Holbach, P.H.T. (2001) The System of Nature (Vol. 1 and 2), Kitchener: Batoche Books, and Le Verrier, U. J. J. (1856). *Annales de l'Observatoire de Paris*, volume 2. Mallet Bachelet: Paris.

[80] See: Poincaré, H. (1993) *New Methods of Celestial Mechanics*, ed. by D. L. Goroff, USA: American Institute of Physics.

[81] Is the problem of how to describe the motion of a number, n, different objects interacting with each other gravitationally. A classic example of this would be our solar system. See: Poincaré, H. (1993) *New Methods of Celestial Mechanics*, ed. by D. L. Goroff, USA: American Institute of Physics.

[82] Geodesic is a curve representing in some sense the shortest path between two points in a surface.

[83] It is the earliest example of deterministic chaos ever studied. See: Hadamard, J. (1898). Les surfaces à courbure opposées et leurs lignes géodésiques. *J. Math. Pures Appl.,* 4, pp. 27-73.

One hundred years after Laplace, Poincaré showed that determinism and randomness are reconcilable in a way, due to long–term unpredictability, and what is now often referred to as ‘non-linearity’. A primarily ‘minor’ cause, which evades us, determines a substantial result that we cannot fail to behold, and so we perceive this result as a product of chance. Nevertheless if we had precise knowledge of the state of the universe, the laws of nature and at the initial moment, we could exactly predict the state of the same universe at a posterior moment. As Longo (2010) reminds us, within the domain of classical physics, we operate with the same equations as God does, with all the promptness of which we can muster, as Galileo had already pointed out[84]. But us, ‘mortals’, unlike god, we do have challenges regarding the physical measurement as well as a different account of the geometry of trajectories determined by these equations: and all this turns out to be extremely crucial for dynamical systems, as Poincaré confirmed. Small variations in the initial conditions may trigger very large differences in the concluding phenomena. This sensitivity to initial conditions and, hence, to fluctuations (perturbations) below the threshold of measurement, entails that predictability is always challenged by this inescapable approximation in the physical measurement. While Laplace’s determinism is ontic and epistemic, Poincaré’s view of chance is exclusively epistemic (the perception of chance is an inevitable consequence of the fact that measurement can never be sufficiently sensitive to initial conditions) and by no means can we recognise truth in anything which goes beyond the relations set out in good theories. Poincaré’s ontological determinism is still viable. As such, it remains Cartesian: deterministic world, external and fallible subject of knowledge. It can only be when the observation ceases to be “external” to the world, and becomes a part of what is “real” (in a non-phenomenological sense) that this is overcome. Which is one of the, less often emphasised, reasons that quantum formalism is so interesting in the context of the gradual elimination of Cartesian dualism from scientific “common sense”.

As Jean Petitot remarked (1975: 145–146), Thom’s morphodynamic structuralism faces the danger of becoming a sort of “neo-mechanicism”. Thus, the critique of epistemological determinism must also address its neo-mechanicist character. This determinism removes any

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[84] “Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth” (6:232; Galilei 1957: 237–38).

ontological significance from the notion of chance, taking it only as the limit-case manifesting the lack of acknowledgement of causes, which would be the fundamental basis of scientific method. The rift between nature and science, which transforms the latter into a sort of simplified representation of the former (mostly because of the acknowledgment of the limits of our intelligence in comprehending phenomena) supports in the end the presumed determinism. Even without being able to perceive the causes, we are ‘driven’ to believe that they do exist. As Jean Cavaillès signalled: “les probabilités apparaissent comme la seule voie d’accès envisageable au chemin de l’avenir dans un monde qui n’est plus doté des arêtes vives de la certitude mais se présente désormais comme le royaume flou des approximations” (1940: 154). Lyotard, counters, in his critique of Thom, that in fact “All that exist are “islands of determinism.” Catastrophic antagonism is literally the rule: there are rules for the general agonistics of series, determined by the number of variables in play” (1984: 59). The ‘faith’ in the preconditions for the consummation of science (i.e. the satisfaction of science's Laplacian ambitions) is a precondition for the deterministic standpoint which is pertinent when trying to comprehend how Poincaré understands chance and probability, since physics sits at the intersection between the imperatives of rationality and the scattered constitution of our experiences. What then does Poincaré designate as chance? It is not a myriad of phenomena which eludes all causal relations (once causal relations are premised in all cases, even when not observed) and it is not merely ‘a measure of our ineptitude’ (bearing in mind that chance, once subordinated to what we call “laws of chance” cannot just bear a negative stamp). Chance, as conceptualized by Poincaré, demarcates ‘cases’ that, regardless of being determined by causal relations, are out of reach for our capacity to analyse them in detail. This situation compels us to take approximate measurements in these cases, which occurs by means of the application of mathematical tools available for the calculus of probabilities. According to Poincaré, probability instantiates chance epistemically since it is not possible to conceptualise chance as a sequence of ‘simply’ presupposed concrete phenomena, as the direct opposite of scientific laws, or as phenomena that are given outside causality. The idea of probability, as a conceptual vehicle proficiently frames chance within the domain of scientific facts when it enables facts to be displayed mathematically in which a given degree of predictive uncertainty is, at least in the short run, inevitable. The refutation of Laplace’s postulation about the total predictability of a causal system by Poincaré helped us to understand classical randomness as a special class of deterministic chaos. He came to understand that highly complex behaviors could emerge in simple nonlinear (the output of a system is not proportional to its input) systems –inherent in deterministic chaos. Additionally, he contributed to the conceptualization of randomness as epistemic, under the domain of deterministic theoretical frameworks. It is important to emphasize that this *causal* domain,

> as framework determining the evolution of a system, comes to include variation, perturbation or fluctuation, even when these are below physical measurement. Or otherwise that a specific trajectory is determined by equations, if possible, as well as by variations/perturbations/fluctuations of its point of origin or of its boundary conditions […] However, this broadened (and weakened) concept of determination no longer implies Laplacian predictability; here is the turning point which provoked such noise, quite righteously, but a noise which has sometimes failed to adequately grasp this broadening of the role of classical determination […] the approximation, specific to physical measurement, acquires a crucial role: it participates to the construction of scientific objectivity in an essential way, by the fact of not being exact. (Longo, 2009: 404)

2.3: Epistemic Probability

In common with Poincare's epistemic interpretation of chance, the "epistemic interpretation" of probability, considers probability a *built-in* feature of epistemic subjects. Hence, contrary to mass, energy or momentum; probability is the epistemic condition of an agent that reasons about a system and not a property of such a system (Finetti, 1975; Savage, 1954; Jeffrey, 1992). We know[85] that the activity of inferring (or estimating, predicting) the state of the world is crucial to brain function. The notions of probability and information are of critical relevance to the computational purpose of the nervous system. This is known as the "Bayesian interpretation". Thomas Bayes was the first to clearly and formally present the idea that probabilities can be conditional on information in what is now known as Bayes's Theorem published posthumously in 1763. This approach tries to be an all-inclusive generalization of the physical interpretation, inasmuch as it is capable of addressing all cases regarded by the latter and additional ones from the calculation of evidential probabilities. This wide-ranging approach of Bayesianism is often tarnished by referring to the subjective interpretation of probability, in contrast to the objective interpretation of frequentism –which will be discussed in due course. But such a depiction is sometimes deceiving, as it is argued that epistemic probabilities can be subjective, objective and everything in between (Berger, 2006; Williamson, 2010). The most common approach to conceptualize uncertainty is

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[85] At least as far back as von Helmholz, H. (1896) Concerning the Perceptions in General. In *Treatise on Physiological Optics,* Reprinted in *Visual Perception*; Yantis, S., ed. (2001), Philadelphia: Psychology Press. pp. 24–44.

considering it as belonging to the domain of knowledge and consequently ultimately *epistemic*. This is made more complex by dividing such uncertainty into: “aleatoric uncertainty” caused by intrinsic randomness (noise inherent in observations) that cannot be further reduced simply by more data, and “epistemic uncertainty” which refers to uncertainty in the model – ie. uncertainty which can be reducible given enough data. “Aleatory uncertainty” is ascribed to results that for ‘practical’ purposes cannot be predicted and are therefore examined as stochastic (e.g., the outcome of coin tossing), while in contrast “epistemic uncertainty” accounts for the lack of information or competence (e.g., whether or not you have the correct answer on a trivia quiz) or deficiency of one’s model of aleatory uncertainty (e.g., whether or not an earthquake forecast is based on valid assumptions).

It is right to say that a *model* of a physical system can have random or stochastic elements. This does not necessarily entail that the researcher really considers the physical system to be “truly random”. The random element generally correlates to an element of the model that is not ‘adequately comprehended’, or not relevant enough, for the researcher to define in its entirety. The researcher has complete knowledge, only, of the model, which she or he constructed. The model typically relates to a conjecture about a physical system, based upon the researcher’s knowledge, and the random elements of the model correspond to our lack of knowledge about the physical system. As stressed time and time again here, from this point of view, we should not confound our knowledge of a physical system with the physical system itself. If we take as an example the field of neuroscience, it is considered of little importance whether an episode, such as the release of a vesicle, is intrinsically random or just unpredictable for the researcher. Nonetheless, models of biological Bayesian inference have counted on this ‘alleged’ randomness to draw probability distributions that are claimed to be based on neural activity but issue merely from measuring frequency distributions of firing rate across time (recurrent “trials”) (e.g. Pouget, Dayan and Zemel 2000; Deneve, Latham and Pouget 2001; Ma et al. 2006). For some of these examples of “Bayesian” models (Ma et al. 2006), the randomness (variability) in the firing rate of a neuron, in light of some stimulus, supplies the source for the uncertainty in the neuron’s approximate calculation of the stimulus. Analogously, this randomness (variability) has been considered as “noise” which could lead to a brain’s uncertainty about the “signal” (e.g. Shadlen and Newsome 1998; London et al. 2010). In most of the aforementioned cases, the scientists did not know the genuine ‘feed’ of randomness, they do not conjecture about it, they do not clarify if the ‘feed’ of the variability is even relevant, and they do not indicate whether they consider this variability as intrinsically random –again, epistemic and ontological noise collapse into one another. However, if this variability is not intrinsically random, and on the contrary it is defined by the information of “ion channels”[86] about the stimulus from the outside, in that case it is unclear why it should entail a correlation to subjective uncertainty. If we assume that there is nothing intrinsically random about neural processes or any other physical system, then it renders transparent the fact that the uncertainty that has been ascribed to neurons in those Bayesian models is in fact the uncertainty of the researchers themselves about the neuron’s processes, which is in turn configured by haphazard decisions of neuronal models and measurement procedures. So either the variability in neuronal firing is apparent (epistemic), in which case they cannot give it any agency (and so it cannot be a source of real uncertainty in Bayesian inference), or the variability in neuronal firing does have some real effect on inference, in which case it is *real variability* –ie *real noise*.

Against this last point of view, and indeed the entire paradigm of epistemic probability we can argue that the physical world itself presents pure randomness on the quantum level of reality. This idea relates to almost all of the interpretations of quantum mechanics. Scientists have to address randomness of experimental outcomes regarding macroscopic variables of their concern; supposing a fundamental random process is a common approach in order to explain such randomness. As an example, ‘collapse theories’[87] present a fundamental stochastic collapse of the wave function onto a specific determinate measurement state, whether strangely prompted by an observer (Wigner, 1961), or as part of a global indeterministic dynamics (Bell, 1987, Ghirardi et al., 1986). ‘No-collapse theories’ must assert as well, that the random outcomes are not reducible to hidden variables. As Antony Eagle puts it: “No mathematical definition of random sequence can adequately capture physical randomness” (2005: 14).

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[86] A protein that acts as a pore in a cell membrane and permits the selective passage of ions. As understood by Hodgkin-Huxley models. See: Hodgkin A.L. and Huxley A.F. (1952) Currents carried by sodium and potassium ions through the membrane of the giant axon of Loligo. *The Journal of Physiology*. 116 (4). pp. 449–72.

[87] A general wavefunction describes the state of a particle, and is a superposition of orthonormal (orthogonal + normalized. Normalized means they are scaled so that their probabilities all add up to 1) eigenstates (the measured state of some object possessing quantifiable characteristics such as position, momentum, etc.). When the particle is observed, it “collapses” into a single definite eigenstate, the probability of which is the square of its amplitude.

Bayes' theorem[88] accounts for the change of beliefs resulting from new evidence, and also procures a mathematically rigorous method to describe the uncertainty rendered in a probability distribution alongside the uncertainty reduction obtained during the inference. This a product of the sophisticated articulation between the notion of information in information theory and the process by which probabilities are updated in Bayesian inference (Ebrahimi et al., 2010). Bayesian inference's continuously 'on probation' design supplies a method for obtaining data (sign) from the phenomenon (object) so as to maximize the expected knowledge gain of the model (interpretant). It also contributes a method for applying data to update models in the form of the Bayesian update. Probability distributions used as models within Bayesian inference have the character of information entropy; the quantity of information which distances the model from certainty[89]. If the log of the probabilities employed in the inference is base two then the information is measured in bits. Bits are the basic unit of distinction. The model's entropy is the number of distinctions which draw it apart from certainty. While the models addressed within Bayesian inference may be kept apart from certainty by any finite number of distinctions the special case of one-bit distinctions from certainty is the case where Bayesian inference resolves into isomorphy with classical logic. Models within Bayesian inference are brought closer to certainty by integrating the effects of data (sign) into the model (interpretant); via the process of the Bayesian updating. Mathematically this is the unique method of moving a model towards certainty (Jaynes, 2003); that is of increasing knowledge. Bayesians have commonly committed the mistake of taking for granted the idea of knowledge as a human feature and that Bayesian inference is characteristic of human affairs exclusively. If, on the contrary,

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[88] Bayes' theorem is the law of probability managing the strength of evidence - the rule indicating how much to revise our probabilities (change our minds) when we learn a new fact or observe new evidence. Bayes' theorem states that for instance, tests are not the event. We have an antibody test for the detection of a virus, separate from the event of actually having the virus. Tests are imperfect. Tests detect things that are not there (false positive), and miss things that are there (false negative). People often use test results without adjusting for test errors. False positives distort results. If we are searching for something extremely rare (1 in a million). Even with a 'good' test, it is likely that a positive result is really a false positive on somebody in the 999,999. We generally prefer the use of natural numbers. Saying "100 in 10,000" rather than "1%" helps people work through the numbers with fewer errors, especially with multiple percentages –"Of those 100, 64 will test positive" rather than "64% of the 1% will test positive". Science is a test. At a philosophical level, scientific experiments are "potentially invalid tests" and need to be treated accordingly. There is a test for a chemical, or a phenomenon, and there is the event of the phenomenon itself. Our tests and measuring equipment have a rate of error to be accounted for. Bayes' theorem transforms the results from a test into the 'real' probability of the event. For example, we can correct for measurement errors. If we know the real probabilities and the chance of a false positive and false negative, we can correct for measurement errors.

[89] This is the same as what I have later called "neg-information" –even though it is model "neg-information" rather than cosmic "neg-information". The concept will be soon discussed in the next chapter.

Bayesian inference is a basic feature of nature, the noise in Bayesian inference is not just the noise in the knowing subject, but is the noise in nature.

2.4: Physical probability

Reductive analyses of probability gave rise to the “frequency theory” of Reichenbach (1949) and von Mises (1957), the “propensity theory” of Popper (1959) and Giere (1973), along with multiple modern accounts, including Lewis’ “best system” account of chance (1994) –see also Loewer 2001.

2.4.1: Frequentism

In its most common application: “frequentism”, entails that the probability of an event corresponds with the associated periodicity of this event in a random experiment that is conducted repeatedly (Neyman and Pearson, 1928, 1933). As in how a color of a flower varies in a seed type, the number of dots shown with each roll of dice, or the number of deaths in an age group (von Mises 1957). According to von Mises, probability stands for the odds of “encountering a certain attribute in a given collective” (ibid.). For him, a “collective” is in this context: a “sequence of uniform events or processes which differ by certain observable attributes, i.e., a set of events from which a certain characteristic is to be observed” (ibid.: 12). On the top of that, it is the “...limiting value of the relative frequency in a true collective which satisfies the condition of randomness” (ibid.: 24). A “true” or “collective appropriate for the application of probability” must unquestionably exhibit limiting values that “remain the same in all partial sequences which may be selected from the original one in an arbitrary way” (ibid.: 24-25). Thus, if all the odd numbered elements are selected, or prime numbers, the selection of an incomplete sequence taking place before the relative frequency is known. This “place selection” (deciding “whether an element should or should not be included” (ibid.)) will show that relative frequency. All sequences, should, then, manifest the same relative frequency, the observation conducted after all the partial sequences have been determined. Randomness, as a consequence, is “place selection” on this premise.

Random sequences are characteristic of a particular kind of chance process: *independent, identically distributed* (Eagle 2016) trials of a process with two outcomes –known as “Bernoulli process”. Still, there are plenty of chance processes that do not show these attributes, and their distinctive output is not product randomness. Frequentism grants a particular role to randomness. As we have seen, probabilities only occur in those mass phenomena (collectives) that can be idealised to a sequence of outcomes. The problem with this methodology is that it emphasises the general sequence to the detriment of the individual outcomes. Hence, fascinating chance phenomena that come to light at the level of individual trials of the repeated processes (single case chances) are overlooked (Hájek, 2009; Jeffrey, 1992). The response from the frequentism *milieu* has been that single-case chance must be part of any adequate interpretation of physical probability. Randomness, as a consequence, encounters the situation in which: if the single-case chances do not fulfil some significant restraints, the resulting outcome sequences generally will not be considered random.

Nonetheless, the frequentist characterization obtained a very positive appraisal from the sciences, because of its simple and pin-sharp formulation (von Mises 1957) – Carnap's own explication of probability$_2$ was in terms of frequencies.

2.4.2: Propensity Theory

The propensity interpretation was presented by Karl Popper in a set of papers in the late 1950s[90]. However, the consideration of dispositional properties as essentially connected to chance had been articulated before: Charles Peirce is to have founded the main ideas behind propensity interpretation in 1892[91]. Popper's intention was to offer an interpretation of the probability calculus. When he presented his propensity notions, Kolmogorov's axioms were already widely-accepted. Consequently, Popper's application of propensity to probability was demarcated by these. Popper's interpretation postulates that propensities are part of empirical reality in the same way as masses and forces are part of the empirical reality reported by Newtonian mechanics. Propensities are therefore neither fictional nor speculative: Their existence is certainly verifiable, and he actually thought that they had been tested[92].

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[90] See: Popper, K.R. (1957) The Propensity Interpretation of the Calculus of Probability and of the Quantum Theory. In Korner & Price (Eds.), *Observation and Interpretation*. London: Buttersworth Scientific Publications. pp. 65–70. and Popper, K.R. (1959) *The Logic of Scientific Discovery*. London: Hutchinson.

[91] Peirce, C.S. (1898) Causation and Force. In Hartshorne & Weiss (Eds.) (1935), *Collected Papers of Charles Sanders Peirce, vol. VI: Scientific Metaphysics*. Cambridge: Cambridge University Press. pp. 46– 87.

[92] See: Popper, K.R. (1959) The Propensity Interpretation of Probability, *British Journal for the Philosophy of Science*, 37, p. 28. and Popper, K. R (1982) *Quantum Theory and Schism in Physics*. London: Hutchinson. pp. 83–84.

Popper adopted a long-run variant of the propensity interpretation. A long-run perspective assumes that a propensity is a property of something like a repeatable series of experimental trials. So, it may only manifest itself as a frequency in the sequence of results of a series of experimental trials in the long run. A single-case perspective, against this background, supposes that the propensity is a property of a single trial and therefore may reveal itself entirely in that very trial.

The long-run perspective can be described in the following way: the propensity to a particular result of a trial is a probability, this corresponds to a distribution over the possible results of an experimental chance configuration, and producing a frequency when the experiment is repeated many times. For example: Suppose that we throw a standard six-sided die, which I know can be considered ‘fair’, each of the faces has a probability of 1/6. Popper’s propensity interpretation, takes this probability as a dispositional property of the generating conditions, or experimental configuration, and it gives rise to a 16.67% frequency when the experiment is repeated ad infinitum. The main problem that Popper finds with frequency theory is the fact that it does not take into account the probabilities of single events.

Popper’s answer to this problem is the modification of the frequentist notion of “collective”. Rather than a collective repeating the same event (*e.g.* throwing a die), Popper talked about repeatable conditions: we do not throw the same die an approaching-infinite amount of times, what we do is pay attention to the conditions inherent in the experimental configuration so that we can recreate the throwing of the die. Popper, thereby, procures a theory of probabilities as propensities inherent in the experimental configuration. This contrasts then with the frequentist view in which probability is a characteristic of outcomes. He highlights the consideration of these probabilities, as part of empirical reality, and therefore subject to the same principles of confirmation as masses or forces. Under this premise, we can consider Popper’s propensity theory the first example of ontological chance we have discussed so far.

Charles Peirce is considered one of the forerunners of the idea of irreducible metaphysical indeterminism or absolute chance. Peirce’s takes on dispositional probabilities follow those on absolute chance, and may even have been anterior[93]. The striking fact is how Peirce’s philosophy of probability coincides with his general “pragmatism”. Today it is common to

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[93] See: Hacking, I. (1990) *The Taming of Chance*. Cambridge: Cambridge University Press. pp. 207–210.

refer to any theory of probabilistic dispositions as a “propensity” theory. Peirce did not use the term “propensity” as such, and it would be a prochronism to associate it with him; but it may be helpful to draw a parallel between Peirce’s view and contemporary “propensity” theories. From Peirceian “dispositional property” we can identify four characteristic attributes: “objectual”, “causal”, “hypothetical”, and “long run”. It is worth examine this notable passage in Peirce’s writings:

> […] The die has a certain ‘would-be’; and to say that a die has a ‘would-be’ is to say that it has a property, quite analogous to any habit that a man might have. […] And just as it would be necessary, in order to define a man’s habit, to describe how it would lead him to behave and upon what sort of occasion – albeit this statement would by no means imply that the habit consists in that action – so to define the die’s ‘would-be’ it is necessary to say how it would lead the die to behave on an occasion that would bring out the full consequence of the ‘would-be’; and this statement will not of itself imply that the ‘would-be’ of the die consists in such behaviour.
>
> Now in order that the full effect of the die’s ‘would-be’ may find expression, it is necessary that the die should undergo an endless series of throws from the dice box, the result of no throw having the slightest influence upon the result of any other throw, or, as we express it, the throws must be independent each of every other. (Peirce, 1955: 169)

Here we can observe already at least three of the four main features of what could be understood as “Peirce’s propensities”. It is noticeable how Peirce inscribes the propensity (the “would-be” property) to the die as such, understood in isolation. That is to say, he poses an ‘objectual’ perspective in which propensities are assigned to the ‘chancy’ objects themselves. This point is in fact a very unconventional approach in the present day. Contemporary theories generally assign propensities to events and not objects. Additionally, the general hypothesis at this time is to assign dispositional properties to the whole experimental arrangement, which contains the chancy object but also a number of additional entities (as well as their properties) and possibly including (on some accounts) the state of the whole universe at a given time. Peirce’s “objectualism” lays at the ground of common dispositional expression. Peirce’s “propensities” are causal in a way that means he does not abstain from assigning causal powers to them. Regarding this, consider the following expressions as applied to propensities in the quoted excerpts: they “lead” (to a particular behaviour), and they have “full consequences” that are “brought out” on certain occasions. Peirce is unequivocal in his work about the nature of causation generally, which he understood in connection with Aristotle’s “efficient causation” (carefully differentiated from the other three Aristotelian notions of causation), from Kant’s notion of causation as the "instantaneous determination of states", and from Hume's notion of causation as "constant conjunction" (Peirce, 1935: 46–87). Furthermore, he unambiguously associated propensity's powers to "efficient causation" (ibid.: 403). The 'conjectural' aspect of Peirce's "propensities" might not be explicit in the text, but it is easily extracted from his work. Peirce's pragmatism drives him to reflect on what difference propensity assignations would make in practice. He realises that the full outcomes of propensities can only be exposed in a long-run (virtual and infinite) series of experimental trials of the same type. In more contemporary terms, propensities exhibit themselves in the adequate repeatable experiments as virtual or conjectural limiting frequencies.

Pierce rejected the idea that there was a basis to adopt the almost universal credo of his time that "every event has a cause" (W 4: 544-554). Pierce's doctrine, which he proposed under the name of "Tychism", was more in consonance with that of Lucretius, who argued for atoms "swerving" in their course for 'no reason': "To the ancients, there was nothing strange in such notions; they were matters of course; the strange thing would have been to have said that there was no chance" (W 6: 204). This entailed that we should acknowledge the plausibility that on "excessively rare sporadic occasions a law of nature is violated in some infinitesimal degree; that may be called *absolute chance*; but ordinary chance is merely relative to the causes that are taken into account" (W 4: 549). In fact, for Peirce the meta-law does not entail a *lawful* universe but a universe that *becomes* lawful. This entails that causation was not always as strong and "as rigidly necessary as it is now" (W 4: 548). In other words, laws of nature are better understood as 'propensities'[94] of nature. Eventually, this ended up being a very important idea for one of the most severe standpoints made by the heterodox polymath George Spencer-Brown, that over time, it is not only magic that will cease to exist, but science itself : "Left to itself, the world of science slowly diminishes as each result classed as scientific has to be reclassed as anecdotal or historical" (1957: 107).

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[94] This is absolutely consonant with Mumford's "dispositionalism" (2001) a contemporary variant that can be contrasted here with Peirce. Munford argues that the dispositional properties of subatomic particles have no ground (or: particles are sets of dispositions).

2.4.3: Spencer–Brown's Probability

Spencer-Brown was a controversial[95] yet brilliant mathematician and logician who fervently examined (1953a, 1953b, 1957), some notable inconsistencies concerning the notion of randomness. He reformulated classical logic in *Laws of Form* (1969) using only a generalized nor operator (marked not-or, unmarked or), that he employs in the style of Peirce or John Venn, by a graphical boundary or distinction mark[96].

To demarcate or interpose distinctions is, according to Spencer-Brown's thought, the elementary (if not the only) activity of human knowledge, a principle that has either shaped or been argued by numerous authors in the radical constructivist field. From cyberneticians such as Ranulph Glanville or Gordon Pask, to archeologists like Cornelius Holtorf. The following passages, from his book *Probability and Scientific Inference* (1957), are illustrative of the points employed by Spencer-Brown in his refusal of statistics and probability:

> Retroactive reclassification of observations is one of the scientist's most important tools, and we shall meet it again when we consider statistical arguments. (1957: 23)
>
> We have found so far that the concept of probability used in statistical science is meaningless in its own terms; but we have found also that, however meaningful it might have been, its meaningfulness would nevertheless have remained fruitless because of the impossibility of gaining information from experimental results, however significant. This final paradox, in some ways the most beautiful, I shall call the Experimental Paradox (1957: 66).
>
> The essence of randomness has been taken to be absence of pattern. But what has not hitherto been faced is that the absence of one pattern logically demands the presence of another. It is a mathematical contradiction to say that a series has no pattern; the most we can say is that it has no pattern that anyone is likely to look for. The concept of randomness bears meaning only in relation to the observer: If two observers habitually look for different kinds of pattern they are bound to disagree upon the series which they call random (1957: 105).

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[95] Inexcusable misogynist and homophobic views on gender and sexuality; as well as his complete reversal into absolute credulity regarding telepathy and other magical thinking can be found in the first (and only) volume of Spencer-Brown's autobiography: Spencer-Brown, G. (2004) *Autobiography: Volume 1: Infancy and Childhood*. Leipzig: Bohmeier Verlag. pp. 97–99.

[96] See: Carnielli, W. (2009) Formal Polynomials and the Laws of Form. In Béziau & Costa-Leite (Eds.) *Dimensions of Logical Concepts*, Coleção CLE, 54, Campinas: UNICAMP.; Edwards, A.W.F (2004) *Cogwheels of the Mind. The Story of Venn Diagrams*. Baltimore, Maryland: Johns Hopkins University Press.; Peirce, C.S. (1880) A Boolean Algebra with One Constant. In Hartshorne, Weiss and Burks (Eds.) (1992) *Collected Papers of Charles Sanders Peirce*, Volume 4. Charlottesville: InteLex. pp.12–20. and Sheffer, H.M. (1913) A Set of Five Independent Postulates for Boolean Algebras, with Application to Logical Constants. *Transactions of the American Mathematical Society*, 14, 4. pp.481-488.

It is worth contrasting this last point with Whitehead's claim, in *Modes of Thought* (1968: 52) that:

> A partially understood pattern is more definite as to what it excludes than as to what its completion would include. As to inclusion there are an infinitude of alternative modes of completion. But so far as there is any definiteness attaching to the incomplete disclosure, certain factors are definitely excluded. [this backs up the 'distinguishing' character of knowledge Spencer-Brown mentions] The foundation of Logic upon the notion of inconsistency was first discovered and developed by Prof. Henry Sheffer of Harvard... [who] emphasized the notion of pattern as fundamental to Logic.

It is interesting to know that Peirce and his student Joseph Jastrow, who popularized the notion of randomization in statistical trials, also faced difficulties with some of the very same problems encountered by Spencer-Brown. For instance, the detection (over time) of distinct patterns or seemingly ordered (sub)strings in a long random sequence.

Marcel Mauss (1972) pointed out that magic equals science in its utilitarian mode[97], since both aim at environmental control, and both will be eaten away by the dredgers of time thanks to the accumulation of patterns out of randomness: "Scientific knowledge, like negative entropy, tends constantly to diminish. It is prevented from dwindling completely into anecdote only by the attitude which seeks to repeat experiments and confirm results without end" (1969: 108). Hence, any meaningful outcome from a finite set of trials is consumed and becomes meaningless as the universe carries on, insofar as, eventually, it will achieve analogous outcomes just by chance. Therefore, we are invariably falling behind, as we must discard one (once-valid) discovery after another.

The parallelism with entropy is captivating, for Peirce made exactly the contrary proposition. So that, in agreement with Spencer-Brown regarding the fundamental nature of probability, Pierce argued that the world was in fact becoming more lawful in the course of time. In the same vein as Spencer-Brown, he considered (W 4: 544-554) the situation where a chance trial like the roll of a die was conducted millions of times. But Pierce pushed forward the physical analogy, and envisioned that the die would become worn down over time. Chance would carve striations in the world which would ultimately become laws.

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[97] We will explore this topic in more detail in chapter 4.

> As everything is subject to change everything will change after a time by chance, and among these changeable circumstances will be the effects of changes on the probabilities of further change. And from this it follows that chance must act to move things in the long run from a state of homogeneity to a state of heterogeneity. (W 4: 549)

Notwithstanding the fact that in thermodynamic terms there is a tendency towards disorganization in accordance with the second law, chance in fact determines movement in the direction of concentration. A chance event is one just when it is a definite one; non-occurrence or vagueness is not a chance event. A group of equal gamblers betting in a random game will come to a place where all the money is in the hands of a single player; "Uniformities in the modes of action of things have come about by their taking habits. At present, the course of events is approximately determined by law. In the past that approximation was less perfect; in the future it will be more perfect..." (W 6: 208). Thereby, Peirce unambiguously thought that this could indeed reverse the predisposition towards increased entropy, and the idea (disturbing to some at the time) that the universe unavoidably must deal with the heat death of organization coming to an end. "Force is in the long run dissipative; chance is in the long run concentrative" (W 4: 551). This might sound counter-intuitive, as we generally tie together randomness with high entropy, with noise, and with pattern disintegration. But absolute chance is the disparateness from law, even from the law of probability.

Spencer-Brown observed that there are conflicting views in the manner in which we employ the notions of probability and chance (1957: 33-48). We refer to probability in terms of inference between propositions, but as well as a feature of events. On the other hand, chance is employed when the outcome was not predicted by the epistemic agent, but also refers to a particular series that has taken place. In order to clarify the way in which we use those terms, Spencer-Brown (ibid.) presented the distinction between what he designated as "primary randomness" and "secondary randomness". The former is "applicable to discrete events," (ibid.: 49) and could be effectively eligible for a conception of ontological randomness. As highlighted by several contemporary researchers within the field of subjective randomness:

> One major source of confusion is the fact that randomness involves two distinct ideas: process and pattern (Zabell, 1992). It is natural to think of randomness as a process that generates unpredictable outcomes, this is a stochastic process according to (GellMann, 1994). Randomness of a process refers to the unpredictability of the individual event in the series (Lopes, 1982, 1987).
> (Falk and Konold, 1997: 306)

The latter designation of randomness is pertinent “only to series of events” (Spencer-Brown, 1957: 49). Secondary randomness removes the relevance of prediction from the equation (insofar as the event has already occurred), and establishes the randomness of a process on the basis of *its output*, which we expect to be a lack of a pattern. Spencer-Brown’s investment in the secondary randomness as a class of probability can be explained on the basis of the available technology of his time, this means, relying on printed tables of random numbers (or Latin squares for factorial experiments). Monte Carlo and several other computational random number generators were not easily available in the 1950s and often unreliable. These can be found ‘unsuccessfully random’ if they exhibit patterns that could be detected by a sharp mind, even if these are the (unlikely) result of entirely stochastic processes. For example, contemporary Bayesian statistics that employ Markov Chain Monte Carlo methods will produce wrong results if the series of random numbers on which they depend on have periodicity (Stern, 2011).

Nevertheless, Spencer-Brown’s classification is an essential and legitimate one, appropriate to address the important distinctions between future and past, potential and actual. The vast majority of the common methodologies of probability refuse to acknowledge this problem by addressing probability as something that takes place in the long run, and as Keynes states, “in the long run we are all dead.” (1923: 80). Peirce and Spencer-Brown’s work coincides as both argued in favour of the requirement of a characterization of probability that is fruitful for the understanding of our world. As a consequence, Peirce provided examples of events with no definite probability (CP 5.14-5.40). He proceeds by selecting a non-convergent mathematical series (that is: the infinite sequence of the partial sums of the series does not have a finite limit), and afterwards devises a game of chance around it. Consequently, we are not able to select the finite series, and try to turn it into the process, by dealing with it as if it were eventually going to become infinite. By means of this distinction, we are aware of the risk of mixing up these two. As stated by Spencer-Brown: “One of the conditions of the probability of event E being ½ is that in a test to verify the statement of its probability we must sometimes get a ratio suggesting, for example, that its probability is 1/20.” (1957: 63). In other words: in accordance with the rules of probability, primary probabilities result in highly dissimilar secondary probabilities. Mainly, our concerns are about the connection of these two. Spencer-Brown (1957: 83) presented the idea of a parallel distinction between bias and stretch. We understand that a series is ‘biased’ if we think of a possible different series from the same source exhibiting a similar bias, while if otherwise, we label it as stretched. The former corresponds to primary probability, and the later to secondary; “Stretch is deviation from a norm. Bias is deviation from an expectation” (Spencer-Brown, 1957: 84). We can think of this in terms of distribution curves too. A “biased curve” is pushed to one side or the other of the normal distribution. The “stretch” is the width of the distribution, or what is usually called the “standard deviation”. According to this, our distinction of probabilities as process and outcome also correlates to potential and actual, future and past.

2.4.4: Best System Account

David Lewis’s Best System Account (BSA) (1994) offers a Humean interpretation of chance. Lewis maintains that the laws of nature are the axioms (or theorems) of the ‘*best systematization* of the universe’. BSA understands chance not as a fundamental physical quantity, but as a sort of ‘statistical collection’ of actual outcomes. This account offers an explanation for the link between chance on one side, and disorder, relative frequency and rational credence on the other side. Lewis defines laws as those generalizations that function in the appropriate way in the best systematization of the facts: “a contingent generalization is a law of nature if and only if it appears as a theorem (or axiom) in each of the true deductive systems that achieves the best combination of simplicity and strength.” (1973: 73). Interestingly, because of Lewis's vaunted Humeanism, this point is close to Leibniz’s formulation of the theory of the best as maximum actual “compossibility” (G III 573). For Lewis, the theory that best combines “simplicity” and “strength” is the *true* theory. We consider a system “simple” when it can be succinctly articulated in a given traditional language. On the other hand, we consider the “strength” of a system on the basis of its informativeness, in ascertaining what chances, in fact emerge in different conditions. BSA supports the idea that objective probabilities exist, described by probabilistic laws. For example: stating that Γs have 60% chance of causing Δs. Lewis (1980) was trying to propose an account of objective chance that resembles the way in which we think of chance when we think of them as propensities, making things unfold in a particular way. In this manner, the laws of nature can account for chance thanks to the postulation of probabilistic laws; which we could state as ‘being true’ if we present another element to consider: “fit”. The “fit” is characterised as the “chance” (assigned by the system) to any potential course of history, inclusively the “actual” realised course of history. “Fit” stands for that “chance” (accounted by the system) of events occurring just as they actually do.

> The virtues of simplicity, strength and fit trade off. The best system is the system that gets the best balance of all three. As before, the laws are those regularities that are theorems of the best system. But now some of the laws are probabilistic. So now we can analyze chance: the chances are what the probabilistic laws of the best system say they are. (1994: 480)

In spite of this, within BSA, chance bears no ‘direct’ relation to the ‘actual’ fundamental nature of things –which we do not have non-mediated access to. If in contrast, we take objective chances as the outcome of the general pattern of events perceived in the world, which dictate what could be considered as a “reasonable credence”, then the general history of the world brings about the fact that objective chances are *facts* consequent upon an immense pattern of perceived events. A major obstacle is faced when ‘the best system’ is in fact deterministic. In that case there are no objective chances (none at all) in the world, since “There is no chance without chance,” Lewis (1987: 120) states. “If our world is deterministic, there are no chances in it save zero and one” (ibid.). In the case that the world is deterministic, the chance of zero or one exists just if the thinking that predicts events within that deterministic world is not determinate; if it were, then there would be no chance, no error and, therefore, no thinking. The possibility of error is the demonstration that chance exists at the very least in that part of the world called thinking. Thus, a system of deterministic laws cannot contain probabilistic laws, as this would be in detriment of the system’s simplicity without any improvement to the system’s strength (which would already reach the highest degree of informativeness). But this is a very problematic interpretation. I want to assert that in fact, objective probabilities *do exist*. That roulette games or radioactive decay actually express objective probability. In spite of this, not all objective chances need to spring from the ‘laws of nature’ -be these deterministic or not. The equation “physical determination = no chances” is an erroneous one. In accordance with Hoefer (2007), we should embrace Lewis’s basic principle; that objective chances are just facts springing from the pattern of perceived events that constitute the world’s history. A certain amount of these chances can be outcomes of natural laws (i.e. a radioactive nucleus has a certain probability per unit time to decay) but other origins for objective probability should exist; i.e. my chance of dying in a road accident. Some objective chances are there to be distinguished in the perceived patterns of events in the world.

The fundamental metaphysical issue for BSA interpretations seems to be; how is it possible to 'explain' a specific case by referencing a regularity? How do we provide an 'explanation' for regularities as such? Unfolding regularities by means of 'more fundamental' regularities will (sooner or later) reach regularities without further simplification. Nonetheless, this is the consequence of BSA characterising "chances" as *outputs* of events, rather than "explanans" of the events as such. There is a degree of random variation inherent in the regularity as we perceive it, however that distribution as such has no explanation grounded on chance. Those 'seduced' by the "propensity interpretation", considering chance a "property" of the event, may see this as a critical flaw. Yet, although BSA cannot sate this metaphysical thirst, no interpretation as yet has been able to. In effect, BSA characterises the concept of chance in connection to our epistemic capacities and needs. There is no epistemic access to underlying propensities, as such, attainable to us today. "Objective probabilities" are better understood in terms of "probabilistic observed regularities".

2.5: Wolfram's Ungrounded Ground of True Randomness

At the very moment when this chapter is being written, British-American computer scientist, physicist, and businessman Stephen Wolfram, claims he may have found a path that leads to a fundamental theory of physics, and that it is "beautiful" (2020). If we think about a dynamical system whose behaviour seems to be random, according to Wolfram (1995), there are two ways in which an apparent randomness can occur. First, it must be clarified that he draws on a very particular concept of randomness: not the natural sciences' idea of "environmental" or "ambient randomness" (i.e. interference or 'noise'), nor chaos theory's randomness that permeates from random initial conditions, but rather a conceptualization of randomness as something intrinsically generated by (or autogenous to) a system. Wolfram distinguishes between "homoplectic" and "autoplectic" type of randomness (ibid.). The former produce macroscopically random behaviour by amplifying the noise in their initial and boundary conditions –any random (or merely complex) input will produce the same or more randomness–, describing an unstable evolution of a system in which perturbations increase. A more speculative "autoplectic" type of randomness, would produce macroscopically pseudorandom behaviour autonomously despite the lack of noise in initial conditions. When it occurs it keeps recreating the same pseudorandom sequence regardlessof noise. In a system like this, an actual random output springs from simple conditions. That is the case of cellular automata[98] (which, incidentally, are also homoplectic). Occasionally, autoplectic and homoplectic processes will interpolate producing computationally irreducible randomness (without the knowledge of all the variables). For instance, we are able to calculate some 'random' details of turbulent air flow using the Navier-Stokes equations[99]. This is autoplectic –intrinsic randomness[100]. Notwithstanding when there are perturbations distant from the origin, then it may be the case of external noise (such as thermal fluctuations) altering values. This is a homoplectic process.

The differences between intrinsic randomness (autoplectic) and randomness from initial conditions are fine-drawn as both share sensitive dependence on initial conditions, in such a way that randomness is 'released' in a deterministic manner, but the difference can be understood in these terms: the former always needs an equivalent of a "pre-individual"[101] (in Simondon's terms) randomness so a causal lineage is triggered, while randomness from initial conditions only needs a 'given seed'[102] that reacts following a small number of guidelines. Intrinsic randomness needs recourse to another system in order to unravel how and what its random initial condition (pre-individual randomness) was capable of (in spite of its randomness) becoming a 'realm' towards itself. Contrastingly, the 'seed', hitherto holds within the foundation of its own 'realm', which it is capable of extending to incorporate other nodes in the network as it develops. Wolfram does not delve into the differentiation between the two *a priori* (he presupposes that a seed is not 'given') but he nonetheless progresses with an account of how these three stochastic mechanisms interact empirically, and how the effects of initial or ambient randomness are eventually exhausted by intrinsic randomness. Also veiled is the distinctness of the underlying structure: "continuous behavior can arise in

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[98] First introduced by von Neumann in the early 1950s as simple models of biological self-reproduction, cellular automata are computational models that are commonly represented by a grid with values (cells). They are characterized by local interaction and an inherently parallel form of evolution, with them, we are able to simulate a large number of real-world systems. Wolfram (2002) differentiates automata in which patterns generally stabilize into homogeneity, automata in which patterns evolve into predominantly stable or oscillating structures, automata in which patterns evolve in an apparently chaotic manner, and automata in which patterns become exceptionally complex and may last for a long time, with stable local structures.

[99] Navier–Stokes equations describe the motion of fluids. We use this to mathematically model weather or systems that entail flow. See: Temam, R. (1984) *Navier-Stokes Equations: Theory and Numerical Analysis*. Providence, Rhode Island: ACM Chelsea Publishing.

[100] As stated by Wolfram in (1985) Origins of Randomness in Physical Systems. *Physical Review Letters*. 55, 5. pp.449–452.

[101] Next chapter will provide a detailed explanation of this notion.

[102] Wolfram employs the notion of "seed" when explaining randomness in computer systems in the appendix to *A New Kind of Science*, p. 970.

systems with discrete components only when there are features that evolve slowly relative to the rate of small-scale random changes.” (Wolfram, 2002: 333) In addition to tackling the question of continuity and “[taking] responsibility for explaining the origins of randomness,” (ibid.: 300) Wolfram’s appeal to intrinsic randomness tries to bring together the probabilistic ‘nature’ of quantum mechanics with the mechanistic character of cellular automata. The randomness produced by autoplectic systems is, in several instances, computationally irreducible, therefore, it is not possible to articulate or model it more neatly by any analytic method. There is no bypass, no way of ‘reverse engineering’ the process or ‘overtaking’ it as it evolves in time. This is an immediate result of Wolfram’s “Principle of Computational Equivalence”. The principle can be expressed in various forms, but Wolfram offers the following elaboration as the most inclusive: “almost all processes that are not obviously simple can be viewed as computations of equivalent sophistication.” (Ibid.: 716-7). This idea presupposes that *all processes*, whether naturally caused or generated by human activity, can be viewed as *computations*. Put differently, this principle concurrently sets up an upper limit and a low threshold for computational sophistication. Thus, our most precise analytic procedures are, on many occasions, insufficient to the complexity produced by even fairly basic cellular automata. There is no equation we can employ to foresee results without knowing the initial rules, no straightforward way of acceding those rules, no iterative method to locate them. Therefore, the probabilistic aspects of quantum mechanics (e.g. indeterminacy) are ascribed to a constitutional deficiency in reason itself. But why, we might ask, the recurrent tendency for epistemological interpretations to collapse into ontological ones? If it is a constitutional deficiency, and reason is, anyway, inherent in nature –then the deficiency is, so to speak, written into the fabric of the cosmos. Nobody knows how the wave function will collapse, and nobody ever can (in this case it is uncomputable), not even God. Thus, we are facing ontological indeterminacy.

2.6: 1-Randomness

We know that randomness of measurement results in the context of quantum mechanics was initially characterised by Born as indeterminism. Indeterminism is a physical explanation of randomness, which in mathematics is most accurately equated with incomputability. Still, there is a more profound understanding of randomness in mathematics, which is what Landsman (2020) in his view of quantum mechanics aims to provide. He presents a notion of

"1-randomness" in which deterministic interpretations of quantum mechanics (like Bohmian mechanics or 't Hooft's Cellular Automaton interpretation) are expressly irreconcilable with the Born rule. Landsman grounds his notion of "1-randomness" in the Mathematical Treatment of the Axioms of Physics[103] (Hilbert's sixth problem), that is: can physics be made axiomatic? He points at how this problem was addressed by both von Mises (1919) and Kolmogorov (1933) in independent and different ways. On one side, von Mises was an inflexible frequentist, probability was for him a secondary notion, subordinated to primarily attaining a solid conception of a random sequence from which relative frequencies characterising probability could be obtained. On the other side, Kolmogorov, began with an axiomatic a priori notion of probability from which a solid mathematical concept of randomness was to be obtained. Despite the general acceptance and continuing realization of his first point of departure, Kolmogorov's unsuccessful attempt to obtain the *denouement* of his project, prompted his later notion of algorithmic randomness, Kolmogorov formalized this notion adopting the theory of computation. Within this frame of reference, Turing machines perform the role of our idealized computing equipment, and we expect that there are Turing machines adequate enough to reproduce any mechanical process which proceeds in a precisely defined and algorithmic manner.

Kolmogorov's algorithmic randomness (*incompressibility*), together with von Mises's lack of success in defining, adequately, random sequences (*patternlessness* (Martin-Löf) and *unpredictability* (Claus-Peter Schnor)), became the three equivalent definitions of 1-randomness (Landsman, 2020): incompressibility, patternlessness and unpredictability. Despite Landsman's own recognition that there is no single "correct" mathematical notion of randomness (2020, Appendix B), 1-randomness is remarkable insofar as it renders a general agreement about the notion. Additionally, it can be characterised in these three tantamount (yet reasonably different) ways, each of which instantiates some basic intuition on randomness.

In 1909, in the middle of his research on the nature of the real numbers[104], Émile Borel maintained that we only have access to real numbers (actually, to any mathematical object) that are renderable or characterizable in a finite number of words, formulated within a

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[103] Hilbert, D (1902) Mathematical Problems. *Bulletin of the American Mathematical Society*. 8, 10. pp 437–479.

[104] Borel, E. (1909) Les probabilités dénombrables et leurs applications arithmétiques, *Rendiconti del Circolo Matematico di Palermo*, 27. pp. 247–271.

language. It is very well known that this notion led to the Richard-Berry paradox, first mentioned in a letter by Bertrand Russell[105]. A version of it can be phrased thus: *define a natural number as the least number that cannot be described in less than twenty words*. Does this number exist? Any answer results in a contradiction[106].

In a similar vein, the proof that Kolmogorov complexity (a string is as complex as the length of the shortest computer program that can generate the string) is not computable arises from the fact that if it was, we would find a contradiction. A contradiction similar to that of the Berry paradox, that is: assuming there is an *exact* way of describing something. Incompressibility dates back to Kolmogorov's work and it is the genesis for various complexity models, such as, Ray Solomonoff and Gregory Chaitin's computational complexity models, Jorma Rissanen's Minimum Description Length (MDL), and Chris Wallace and David Boulton's Minimum Message Length (MML). All these types of complexity models can also be employed to effectively bridge the gulf between Spencer-Brown's notions of "primary" (applicable to discrete events) and "secondary" (applicable only to series of events) randomness, evidencing that they are comparable –or even equivalent[107]. Chaitin in line with Kolmogorov, states:

> something is random if it is algorithmically incompressible or irreducible. More precisely, a member of a set of objects is random if it has the highest complexity that is possible within this set. In other words, the random objects in a set are those that have the highest complexity. (2001: 111)

Both Kolmogorov's complexity and Chaitin's "information compressibility" share the view that if we cannot tell what has generated a string of characters, such a string is random. Chaitin's Theorem provides a novel and illimitable kind of unprovable but true statement: "Since complexity has been defined as a measure of randomness, this theorem implies that in

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[105] Griffin, N. (2003) *The Cambridge Companion to Bertrand Russell*. Cambridge University Press. p. 63.

[106] We can describe numbers with words. For instance: "the first prime number bigger than five" is a valid description of 7. Sentences can also refer to themselves. i.e.: "this sentence has five words". The paradox arises when we combine these two propositions in the right way: "the smallest positive integer not definable in under eleven words" This sentence defines a number and the description is ten words long. However, by definition of the number, it cannot be defined in under eleven words. The sentence contradicts itself.

[107] See: Chaitin, G.J. (1975) Randomness and mathematical proof. *Sci. Amer.*, *232*, pp. 47–52.; Chaitin, G.J (1988) Randomness in arithmetic. *Sci. Amer.259*, pp.80–85.; Rissanen, J (1989) *Stochastic Complexity in Statistical Inquiry*. New York: World Scientific; Kapur, J.N (1989) *Maximum Entropy Models in Science and Engineering*. New Delhi: John Wiley; Kac, M (1983) What is random? *Amer. Sci.*, *71*, pp. 405–406.; Wallace, C.S. (2005) *Statistical and Inductive Inference by Minimum Message Length*. New York: Springer.

a formal system no number can be proved to be random unless the complexity of the number is less than that of the system itself". (1975: 52)

So each of these mathematical attempts trying to demarcate randomness fail in this Sisyphean task. In words of the topologist Hans Freudenthal: "It may be taken for granted that any attempt at defining disorder in a formal way will lead to a contradiction. This does not mean that the notion of disorder is contradictory. It is so, however, as soon as I try to formalize it". (1968: 9-10) This is interesting, because it perhaps suggests (though he does not argue this) that "disorder" is a first level predicate only, i.e. is incapable of higher logical levels or logically inscrutable, yet nothing more than that predicate.

It would appear that patterns in nature entail regularity, order and, perhaps, underlying mathematical structure. The inaugural accurate definition of randomness for sequences of bits was supplied by Kolmogorov's former student Martin-Löf in 1966[108]. While in a string like 111000111000111 exhibits a clear pattern; a string like 011111100111101 does not. It is also possible that a string could appear to have a pattern in its initial segments but then turn out to be patternless. Martin-Löf's randomness argues that a non-random string has a finite *pattern* and keeps that pattern for the duration of a potentially infinite length. Thus, a string is random when it lacks a pattern, similar to Spencer-Brown's secondary randomness (1957) where the randomness of a process is understood from its lack of pattern. In other words, "an infinite number that is irreducibly random is one that cannot be described by repetition of a finite string; a Martin-Löf random number lacks a pattern that can be generated by any (necessarily finite) algorithm" (Bradley, 2016: 72). Martin-Löf's characterization regularizes the idea of a string "having a pattern" by stating that it pertains to a "computably enumerable set", that is: there is an algorithm (i.e., a Turing machine that recognizes the set) that can enumerate the elements of the set. By doing this, he introduced a measure-theoretic approach. His notion is based on effective stochastic laws that measure the random probability distribution.

In the same way as Martin-Löf, Claus-Peter Schnorr tried to improve the work of von Mises. Schnorr's adoption of the unpredictability approach is equivalent with game-theoretic randomness. Gambling strategies which take into account the amount of a bet is technically called martingales. There is a martingale process where (at even odds) the stake is doubled

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[108] Martin-Löf, P. (1966) The definition of random sequences. *Information and Control*. 9, 6. pp. 602–619.

each time the player loses. Gamblers follow this method because, eventually they will win. According to Schnorr, for a sequence of binary digits, to be random is to be unpredictable or *impossible to win* (no gambling system can win when playing on the sequence) (Schnorr 1971a, 1977).

Along these lines, we can see how the requisite of incompressibility (Kolmogorov–Chaitin), patternlessness (Martin-Löf), and unpredictability (Schnorr) for randomness concur, which is without a question, very exceptional[109].

2.7: Ontic Randomness

A more profound question that I would like to consider is ontic uncertainty: the randomness of nature itself. If randomness has an irreducible origin the fundamental laws must afford the instantiation of alternative events under *equal* terms. Ontic probabilities are generally understood as probabilities which belong to the ultimate fabric of reality and they are "built-into nature" independently of the existence of an agent that is around to attain knowledge about them or not. If ontic probabilities are truly "built-into nature", it is because they are derived from some "probabilistic" component in the world –a degree of fundamental randomness in nature, by virtue of which events are as they are.

To think about fundamental randomness leads to, on the one hand: quantum indeterminacy and the alleged necessary incompleteness in the description of a physical system, and on the other hand, the conception of a mathematical system as consistent only when it is incomplete. The latter appears to be the case where a mathematical system exhibits sufficient strength to manage integer arithmetic. Such systems entail unprovable mathematical facts that just happen to be true. To put it differently, a mathematical system has to deal with incompleteness in order to achieve consistency. Chaitin-Kolmogorov Complexity is a straightforward consequence of Turing's halting or uncomputability problem[110], which in turn is in practice a translation of Gödel's incompleteness theorem in the domain of computer science. In a nutshell, the halting problem claims that it is not possible to have a general

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[109] The correspondence between the criteria of Martin-Löf and of Kolmogorov–Chaitin was demonstrated by Chaitin (Calude, 2010, Theorem 6.35) and by Schnorr (1973). The correspondence between Martin-Löf and Schnorr owing to Schnorr (1971b), Staz 5.3. See as well: Downey & Hirschfeldt (2010), Theorems 6.2.3 and 6.3.4.

[110] Turing, A. (1937) On computable numbers, with an application to the Entscheidungsproblem. Proceedings of the London Mathematical Society, Series 2, Volume 42. pp: 230–265.

algorithm that will decide whether the program will finish running, or continue to run forever. Gödel's incompleteness theorems[111] claim that a formal axiomatic system generates inconsistent theorems if it is complete –conversely, if incomplete, it is a consistent formal axiomatic system. This means that it will have nothing to say about never-endingly true mathematical statements.

There appear to be irreducible 'lacunas' in the "laws of nature" (as currently understood and formulated by the natural sciences) that indicate their incompleteness[112]. This enables the incidence of events without any singular natural (immanent, intrinsic) cause. Contemporary quantum mechanics entails non–determinism and irreducible randomness. As has already been remarked by von Neumann (1955), accepting the idea of irreversible measurements falls in contradiction with the unitary deterministic evolution of the quantum state. Put differently, randomness is fundamental in quantum physics as we understand it, and the collapse of the quantum wavefunction is in fact random. Quantum mechanical processes are probabilistic and not deterministic, we cannot predict the outcome of an experiment; it is only possible for us to assign probabilities to different outcomes. This could be the case due to the so-called local hidden variables that we have not yet discovered, or because quantum mechanics entails actual randomness. There are no variables that rule the result. One proposed way to test whether those local hidden variables exist is "Bell's Inequality" (1964). If it is violated, there are no local hidden variables[113]. Thus, quantum systems have the ability to ensure a robust form of randomness which is not possible to assign to an incomplete knowledge of any classical variable of the system.

One way of thinking about such randomness is in terms of Turing's 'oracle'. The task of delivering a randomly selected real number, an unprovable truth, or the value of an incomputable function, can only be carried out by an "oracle". Alan Turing presented this notion of an oracle in his Princeton Ph.D. thesis, later published as *Systems of Logic Based on*

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[111] Gödel, Kurt. (1931) Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme, I. *Monatshefte für Mathematik und Physik*, v. 38 n. 1. pp: 173–198.

[112] Not because the laws of nature are themselves incomplete –so that a complete account is, in principal, impossible. A scientist would say that: "still there is job to be done" in order to achieve a (for instance) satisfactory account of gravity in the standard model of particle physics, quantum indeterminacy in general relativity etc.

[113] So far, however, only local violations of the Bell or Leggett–Garg (see: Leggett, A.J. and Garg, A. (1985) Quantum mechanics versus macroscopic realism: is the flux there when nobody looks? *Phys. Rev. Lett*. 54. pp. 857–860) inequalities have been demonstrated using superconducting qubits. See: . Ansmann, M. et al. (2009) Violation of Bell's inequality in Josephson phase qubits. *Nature*, 461. pp. 504–506 and Palacios-Laloy, A. et al. (2010) Experimental violation of a Bell's inequality in time with weak measurement. Nat. Phys. 6. pp. 442–447.

Ordinals (1939) as “some unspecified means of solving number-theoretic problems; a kind of oracle as it were. We shall not go any further into the nature of this oracle apart from saying that it cannot be a machine” (1939 :172–173). If such an oracle exists, it is an agent in a position of making a choice, for instance: a random number choice. A choice or decision which cannot be made by a universal computer. An oracle is an abstract machine, a black box, this notion is generally applied in computer science to denote an input channel that feeds a computer program by supplying information and choices that the program requires. “Imagine there was a cupboard, and you put something into the cupboard, and when you open the door again, it has a post-it note with the object’s KC [Kolmogorov Complexity]. All of a sudden, KC can play a causal role in the world. Computer scientists call this an Oracle” (DeDeo, 2020: 5).

If we picture the universe as a computer, an oracle is required to choose the outcome of quantum or chaotic collapse events, which cannot be computed within the universe. Let us consider transcendent agents, interacting with(in) a(n) (in)deterministic world via suitable interfaces: the user interface of a video game. This real-time computer system receives input from ‘the outside’. For instance, a game set in an open world like *Death Stranding* (Kojima 2019). Human players are transcendental within the terms of the framework of the videogame’s world, and are conditioned to their own world, where they live –as well as the user’s interface. However, the world of *Death Stranding* is itself completely deterministic in a very particular manner: it enables the player’s input from ‘the outside’; but apart from this, it is generated by a computation. We can picture *the player* as a special type of indeterministic (with regards to intrinsic sources) oracle. Presumably, an agent from ‘the outside’ (you might want to consider this agent God) ‘pilots’ our world (gently but ‘determinedly’) using an oracle, a computing interface to a system, that enables input from ‘the outside’ via fundamental lacunas in the natural laws.

In agreement with the violation of Bell’s inequality in quantum mechanics, the universe is ‘mobilised’ by irreducible randomness at its ‘crux’. Following Turing‘s uncomputability and Kolmogorov-Chaitin complexity, computation of irreducible randomness needs an oracle, which, in the present form of our computational understanding is boundlessly powerful. Mathematics appears to state, and physics appears to corroborate, the possible existence of the oracle – this supplies choices to a universe that, without a primary ‘pilot’, does not know what to do. This could be depicted as an immensely complex network of coupled collapse events all over space and time, determinedly driven by the oracle.

To depict the universe as a massive computer entails the implication that what is uncomputable has no causal power. DeDeo (2020) remarks that at least one uncomputable object; Kolmogorov Complexity (KC), does play a causal role in the physical world, and that we have proper scientific grounds to consequently think it exists. DeDeo uses a combination of arguments, in conformity with the probabilistic extension of algorithmic information theory, to reveal that such a causal role is not only in accordance with our current knowledge from cosmology, but also anticipates an enigmatic attribute of our environment: mutual explainability: “ the fact that things that tend to correlate with each other also tend to explain one another.” (2020: 1)

> Explanation here is to be taken in the deep, Kolmogorov sense: in these universes, if samples of *a* correlate with samples of *b*, then even though a, on its own, looks complicated, you can (on average) find a simpler explanation for it once you know *b*. This also goes the other way: if you see that a is easier to explain given *b*, you ought to expect the processes that generated them to be statistically correlated
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> […]
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> The idea that mutual explainability provides evidence against the physical Church-Turing Thesis is radical. The standard (in computerland, “normie”) story of how we explain gestures to a background of expectations that come from biological evolution. Yet while evolution can account for some of our ability to explain what is correlated, it cannot account for the explainability itself. It is also limited in its ability to account for why we are able to make progress on problem types we never evolved to explain, such as the structure of the atom.
>
> It also can’t explain the nature of that progress, which is characterized by, among other things, the unreasonable effectiveness of mathematical reasoning. That includes not only that any particular piece of mathematics works, but also how mathematical simplicity has served as an anticipatory pointer to good explanations. (2020: 6)

DeDeo addresses the fact that the algorithmic mutual information, on average, approximates the Shannon mutual information only if the initial probability distribution is of low KC, and hence, if we find that whenever things are correlated (mutual information measures correlation), they are also co-explainable, we acquire information from the details, of the initial probability distribution’s KC. From this perspective, KC has engaged in the arrangement of our world; no entity with access only to computational resources could have set things up this way. If there is such a thing as God, she has to have access to an oracle.

2.7: Conclusion

If randomness is ultimately irreducible, the obvious realist claim is that it is antecedent to order. However, this presupposes an identity to randomness in the absence of order obtaining, de-randomizing it accordingly yet with the consequence that randomness would be, as reported in this chapter, for everyday thinking, “given”. The alternative has to be the emergence of randomness as prior just when some order obtains that has a lesser extension than what it issues from. An asymmetry or non-isomorphism between randomness and order is necessary. This could satisfy both realists and nominalists, since randomness is not given as antecedent but becomes it once a non-original order obtains.

The contrast of noise as an ontological or psychological phenomenon can be thought of in terms of that between predictability and unpredictability - i.e. the possibility of prophecy (Goodman’s “forecast”). This is interesting precisely because the time-independent function of prediction remains the goal of science as of the Oracle at Delphi, demonstrating not the irrationality of the former but the rationality of the latter. The key difference lies in their respective criteria of accuracy in prediction.

This can explain the disparate character of epistemic and ontic randomness: the former is reversible (no dissipation) while the latter is irreversible (entropy increases with time). It is worth pointing out that epistemological interpretations constantly balance on the precipice of becoming ontological. They are generally held back from becoming so by blind faith in deterministic processes that cannot, sometimes in principle, be detected. Something is wrong when science has to be protected by blind faith of this sort. It is an indication that the epistemological interpretation must be wrong. One more time, we are confronted here by the old dispute between Boltzmann, Loschmidt and Zermelo[114] about the reason why a macroscopic system (particle and instrument) formed from many microscopic objects can obtain a property (irreversibility of evolution) that its elementary constituents do not possess. The solution returns here to the reaffirmation of the principle under which the major part of evolutionary paths lead from less probable to more probable states. Now, the enquiry about

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[114] In 1872, Boltzmann developed a theorem (*H*-theorem) which appeared to demonstrate that the irreversible transition from any non-equilibrium state to the equilibrium one was a result of Newton’s law. Later in the 1870s, Loschmidt (1876) and Zermelo (1896) turned down Boltzmann’s conclusion and provided counterexamples demonstrating that Boltzmann point was indefensible. See: Wu, T.Y. (1975) Boltzmann's H theorem and the Loschmidt and the Zermelo paradoxes. *International Journal of Theoretical Physics*. 14 (5). pp: 289–294.

timing appears: at what stage does randomness appear? The ‘orthodox’ solution tends to be: the evolution of the wave is reversible and deterministic, while the measurement introduces irreversibility and randomness. This goes against the common presumption of realism, which sustains that the result of a measurement is not ‘created’ by the measurement, but correlates with the properties held by the measured system prior to the measurement. Needless to say, this explanation brings in a lot of issues of a fundamental nature: on the role of the ‘observer’, on the capacity of human’s mind to influence ‘reality’ et cetera.

Quantum randomness and its mathematically homologous: Gödel’s incompleteness theorem, Turing’s uncomputability, and Kolmogorov-Chaitin complexity, propel us to one onerous judgement: our world is not only epistemologically but ontologically incomplete, that is, no matter what system we try to assess, to gain a consistent image, (precisely what science is trying to do), it will constantly fail to account for itself by itself, demanding a larger framework and system within which to be meaningful. This is the asystematicity announced by the asystasy, the constitutive aporia in knowledge, which relapses with the creation of systems of knowledge. Different fields emerge to ‘seal’ their intensive (un)grounding just as this disunity grounds all knowledge.

Chapter 3: Noxiogenesis

3.1: Introduction to the Chapter

Our inquiry about noise needs to address both the question of information and the question of the emergence of order. The former has been addressed in the first chapter in terms of the different characterizations of entropy. In this chapter, I will try to account for the latter. Gilbert Simondon was the first true philosopher of information. Thanks to his engagement with constructivism[115], as well as the rich tradition of American cybernetics[116], he provided

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[115] Here we can understand constructivism basically in relation to its rejection of technological determinism. How technical artifacts cannot be fully accounted by the technical logic of their functioning. The development of technology is shaped not by technical and scientific progress but by contingent socio-cultural, political and economic forces. As we will see, for Simondon, “information constructivism” is a product of external forces that renders information an effect of these relations.

[116] McCulloch, Wiener, Rosenblueth, Bateson, Bigelow, von Neumann, etc. See for example: Kline, R.R. (2015) *The Cybernetics Moment. Or Why We Call Our Age the Information Age*. Baltimore: Johns Hopkins University Press.

one of the earliest and most rigorous philosophical critiques of the mathematical theory of communication. He highlighted the fact that information is not a thing, but the operation of something reaching a system and producing transformation in it. His informational ontology is (still today) an important counter, from the field of philosophy, to the informational perspective of the hegemonic tradition of engineers and cyberneticists such as: Shannon, Weaver and Wiener. Additionally, his theory of individuation stands for the ontogenetic emergence of form (or information). Simondon's elaboration of his primary and secondary thesis in *L'individuation à la lumière des notions de forme et d'information* (ILFI, 1964/1995), *Du mode d'existence des objets techniques* (1958/2012) and *L'individuation psychique et collective* (1989/2007) were prior to the development of the sciences of complexity, chaos and self-organisation. Notwithstanding this, and as we will see, the "neotechnic"[117] hypothesis that he constituted from the field of philosophy, explores the genesis of organised structures in states outside the thermodynamic equilibrium. These so-called "metastable" states are not in true equilibrium, and therefore cannot be directly treated by thermodynamics. A metastable system may endure different alterations while keeping a state of apparent equilibrium –in Rene Thom's terminology we would say that it retains its "structural stability" (1972).

In this chapter I present Simondon's theory of information and metastability, that I take to be extremely compelling for the question of noise because it articulates both his concept of "transduction" and noise, and how these are never independent of their material medium when patterns are being transferred. Noise becomes inseparable from the milieu that it operates in.

I will flesh out Simondon's ontology of individuation, highlighting its relation to theories of self-organization and indicate how this is based on the interrelations of *structure and operation,* in which determinism and indeterminism are borderline cases. Finally, I will cover his theory regarding the genesis of the individual and what is the role of noise in the

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[117] According to Lewis Mumford's *Technics and Civilization* (1934) the neotechnic phase begun in 1820 and it is based on electricity, it anticipated what would later come to be called cybernetics, since Mumford already acknowledges that causal relationships between technology and social order cannot be unidirectional, but to resemble a feedback loop. See: Mumford, L. (1934) *Technics and Civilization*. New York: Harcourt Brace.

questions regarding emergence and organisation. To give a better demonstration of my argument, I will draw on Nelson Goodman's syncategorematic nominalism.

3.2: Noise in Relation to Simondon's Notion of Metastability

Metastability appears in Simondon's work as one of the requirements of the process of individuation. As we have just seen, it refers to a specific state of a system, whereby any change can shift the system to a new state or cause it to undertake a "phase transition". Simondon calls individuation this process of phase transition. Since individuation is a never-ending and never completed process of emergence, we need a term transcending the classical opposition between stability and instability. Metastable potentially fulfils the requirements of every actualisation of this opposition. Metastability is where a dynamic system occupies one particular attractor state within its phase space. External perturbation can bring about a shift (bifurcation) to another attractor state within the phase space. Each attractor state is "metastable" –but the system as a whole is far-from-equilibrium. A given system is capable of changing to a more stable or more complex state and still contains a degree of the "pre-individual", which is open for new transformations, new processes of individuation. The pre-individual is the very state of metastability (and not a substantial ground) that each individuation makes possible. The "pre-individual" is the entire state/phase space. Every possible state that the system could occupy –a kind of potential design space. Metastable states are those states within this "pre-individual" state-space that the system can actually occupy for any length of time –the attractor-states. The pre-individual nature is the primitive unity from which both the individual and its associated "milieu"[118] are split (de Boever, et al. 2012: 96).

No structure which is entirely invulnerable to transformation can exist. Forms are relatively enduring results of processes of transformation. Some elements of the process, such as singularity states or the contingent potentials of the situation in which the system is specified

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[118] The term milieu has its roots in the philosophy of nature, where the French term "milieu" was used to translate the English term "medium", which appeared as a pivotal notion in XVIIth century mechanics as defined by Newton (1728), see: Newton, I. (1728) *Optical Lectures Read in the Publick Schools of the University of Cambridge*. London: printed for Francis Fayram. Simondon's approach of the term, represents a continuation within a genealogy of the concept that starts with Auguste Comte and permeates von Uexküll, Lamark, Darwin and Canguilhem.

within its metastability are the elements that enable the transformation process to be triggered.

If entropy is defined as the measure of disorder in a system; "Information is –in the transmission of a message– what is opposed to the general levelling of the energy modulated by the signal" (ILFI: 221; my translation). This is what allows us to distinguish between the possible states of a system. In a carrier wave in which there is a "levelling of energy" – i.e. no modulation (continuous sine-wave at the same amplitude and frequency) – there is no information. So, information is that which opposes this "levelling" of the pure carrier sine-wave - it is identical to any degree of modulation (of amplitude or frequency). As an example, Simondon states that to photograph sand, film grain must be smaller (which means a greater ability to distinguish) than the grain of sand photographed (ILFI: 221-222).

3.2.1: Simondon's Theory of Information

> [T]o be information presupposes that there is a tension in the system of the being: the information must be inherent in a problematic, since it represents that by which the incompatibility within the unresolved system becomes an organizing dimension in its resolution. The information implies a change of phase in the system because it implies the existence of a primitive preindividual state that is individuated according to the dictates of the emerging organization. (Simondon, 1992: 310-11)

Simondon's proposal concerning information asserts temporary states of negentropy that face the prospective backdrop of entropic equilibrium –heat death. In the first chapter we have seen how Wiener understood information as the unit of measurement for order. From this standpoint, he further suggested that information is negentropic insofar as it is opposed to the energetic processes of degradation within the system. Simondon reversed Wiener's proposition. It is necessary to input some energy (a signal) into the system if we want to transmit information, but there is no constant mathematical relation between the quantity of energy applied to a system and the quantity of information transmitted. This is demonstrated with a brief example. In order to avoid the signal degradation and enhance the transmission of information, we have two options:

1. We can increase the signal energy (increasing the total amount of energy in the system).
2. We can decrease the background noise by reducing the gain input of the signal.

Option (2) demonstrates that the diminution of the total amount of energy in the system improves the transmission of information only if a different distribution of energy within the system allows it. In other words, the actual distribution of energy in a system, i.e. its form or quality, is that which determines the dynamism of the signal against its background, and subsequently the quantity of information that can be transmitted. A signal should not only be sent trying to avoid randomness (degradation of energy), but has to have a signification, an efficacy for the receiving mechanism. That is to say: it must be able to integrate itself effectively into the operation of the latter. Therefore, Simondon argues that: "the magnitudes[119] relating to the transmission and the magnitudes relating to the significance are antagonists" (2005: 222, my translation). This amounts to the fact that there must be a "carrier" of the information, and the carrier cannot be entirely 'silent'. Information relies on the fact that the medium (carrier) is modulatable, and, accordingly, never really 'silent'.

Thus:

- There is a better transmission with signals that are not confused with the uniformity of the predictable.
- For a reception to take place, an analogy is required between signals sent and those that hypothetically reach the receiver: it is necessary that the signals are almost predictable.

It is therefore a relational aptitude belonging to the global system composed of emitter, signal and receiver. The actual existence of information is given by the connection between this aptitude and predictability. Absolute-predictability would be the complete coincidence between the signal and the receptor structures. This is not information but "exterior iteration of an inner reality" (2005: 223, my translation). Absolute unpredictability would be the total divergence between the signal and the receptor structures. The signal cannot have meaning,

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[119] The use of the expression "orders of magnitude" derives from the scientific notation of very large numbers in which each order of magnitude is ten times the previous one.

cannot be integrated, it is not significant: There is no information. These two poles mark the extremes between which information is possible: “The signals to be received, must find *previous forms* in relation to which they are *significant*; the signification is relational” (ibid.). We can see that the fundamental aspect of Simondon’s concept of information is the fact that information is not a signal, but a structuring activity. We find, therefore, four actors: signal emitter, signal (what is transmitted), form (structure of the possible signal receiver), and information (what is effectively integrated into the operation of the receiver after the test of disparity between extrinsic signal and intrinsic form). But, in this operation, where can we find the role of noise in the emergence of order? It may be traceable through the trail of Simondon’s “transduction”.

> Transduction denotes a process – be it physical, biological, mental or social – in which an activity gradually sets itself in motion, propagating within a given area, through a structuration of the different zones of the area over which it operates. Each region of the structure that is constituted in this way then serves to constitute the next one to such an extent that at the very time this structuration is effected there is a progressive modification taking place in tandem with it. (1992: 313)

3.2.2: Transduction

The Swiss developmental psychologist and philosopher Jean Piaget (1945/1962) designated “transduction” as a term related to a mental operation that is different from both the deductive and inductive operations. It is not difficult to derive the same understanding of transduction in Simondon, but we should highlight that in Simondon’s work, “transduction” (in the first place) stands for the process of individuation. Transduction is any transference of information through a material medium: his famous example for this is the growth of a crystal (the same as in the example of self-organisation in a snowflake formation), where transduction mediates different organisations of energy within any processes of differentiation and crystallisation. Transduction can also be seen as the propagation of the form. The transmission of information via the material medium of language and soundwaves (for example) is no different in kind to the transmission of ‘information’ through a crystal as it grows. Both are sub-categories of the same general morphogenesis. Individuation is triggered by the process of the integration of disparity – there is a “disparate” condition, i.e. there is not a “phase coincidence” between the “angles” of the system. Simondon adopted the notion of “disparity” borrowed from optics to describe the way in which stereoscopic vision combines two images into a single perception, to disentangle the genesis of beings. Without a phase difference or a phase offset, a system cannot surpass its state of saturation. The “change” in the informational properties of a system is itself transduction. It signifies the encounter of two disparate informational fields and ushers in the individuation which will result into a new informational structure which actively solves the disparity between fields[120]. Form or information is modulated within this transductive operation. If we hold that morphogenesis is the emergence (and not just a change) of form, we can comprehend what Simondon is suggesting when he states that: “The notion of form must be replaced by that of information, which implies the existence of a system in metastable equilibrium that can individuate; information, the difference in shape, is never a single term, but the meaning that arises from a disparation” (Simondon, 2007: 28). Thanks to the action of this disparity, this activity spreads the pattern in a progressive way. Simondon names this progression “transductive propagation”, which spreads within the system, producing a new state of equilibrium. An individuation (the very genesis and constitution of forms and how they differ from one another) and its “milieu” are mutually determining and each are expressions of information within a feed-back process of mutual self-shaping. We now understand how morphogenesis is better understood in terms of modulation than of moulding. As he makes clear: “[i]ndividuation is a modulation” (2005: 219). We can describe the behaviour that noise generates using Simondon’s “transduction”. Adrian Mackenzie, in his book *Transductions*, writes:

> For the process of transduction to occur, there must by some disparity, discontinuity or mismatch within a domain; two different forms or potentials whose disparity can be modulated. Transduction is a process whereby a disparity or a difference is topologically and temporally restructured across some interface. It mediates different organizations of energy. The membranes of the microphone move in a magnetic field. A microphone couples sound waves and electrical currents. (Mackenzie, 2002: 25)[121]

In this sense, the transducer acts as the heart of the microphone, a transducer converts a signal in one form of energy to a signal in another form of energy. In the case of the microphone, it converts sound in air into an electrical signal. Noise becomes inseparable from the milieu that

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[120] This is reminiscent of Deleuze’s “problem idea” (2004). A virtual morphogenetic tension/intensity that constantly resolves into actualities, and further vital intensities. An energetic dynamism with no “final solution”. Deleuze found Simondon’s “profoundly original theory of individuation implying a whole philosophy” (2004b: 86). For a detailed account of Deleuze’s Idealism see: Dunham, J., Grant, I.H. and Watson, S. (2011) *Idealism: The History Of A Philosophy*. Montreal, Quebec: McGill-Queen's University Press. pp. 286-293.

[121] This could be understood in terms of what Deleuze describes as the ontological priority of “pure difference” (1990). Difference/disparity that precedes form/identity. While Deleuze’s concepts were clearly inspired by Simondon, it would be too bold to consider Simondon’s “information” the same as Deleuze’s “pure difference”. Relevant to this connection, see: Daniela Voss (2018) Simondon on the Notion of the Problem. *Angelaki*, 23, 2. pp. 94-112.

it operates in. Both transduction and noise are never independent of their material medium when patterns are being transferred. We know that medium and message converge in communication just as in nature, and the medium determines to a great extent what will be the "shape" of the information transferred; if it is modulatable it cannot be 'silent'. Is Simondon claiming that *nature is communication*?[122] This seems at least arguable. But, if "nature" *is* "communication" we would need another communication processing agent built in nature in order to conceive it as such, this would produce a recursive loop that presents problems to such equivalence. But clearly, for Simondon, information is extended far beyond the transmission of data between two predetermined elements, it is the ontogenetic production of the system itself, through which the system is produced inwardly. Rather, information assigns the elemental process by which being itself is expressed or originated through dynamic interactions with other beings and the associated milieu.

3.3: Individuation and Self-organisation

We can find numerous instances of self-organisation in nature. One straightforward example of a physical, structural, phase transition process, is the case of the crystal growth. The mechanisms and driving forces of this kind of growth require some kind of entry-level scientific understanding, but anyone can appreciate the arrangement in an orderly repeating pattern of a snowflake formation or the frost patterns on a window—the product of the dendritic crystal growth. Also, the stripes on zebras or tigers may serve as an example for pattern formation on furs or skins of fish[123]. It is even easier to understand at first glance the behaviour exhibited by a population of bees shimmering in response to a predator. The scientific study of self-organising systems is the attempt to discover the general rules under which such structures appear, the forms which it can take, and methods of predicting the changes to the current arrangement that will result from changes in the underlying system.

The "order-from-noise principle", which was first proposed by Heinz von Foerster (1960), establishes that noise or random perturbations will help a self-organising system to find more stable states in its adaptive landscape. In an adaptive landscape model, all attractors[124] are not

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[122] Reminiscent of our mention of Bayesian inference understood as a basic feature of nature.

[123] The original idea for an explanation of this can be found in: Turing, 1952.

[124] As we have seen in the first chapter, an attractor can be thought as the preferred position for the system. Any system that moves to a determined structure can be said 'to be drawn to an attractor'.

equal: those with a higher adaptiveness are in a sense more favourable than the others. This is how this works: though a system may be said to be drawn to an attractor, the attractor “itself” cannot be said to be doing the drawing –there is no subject behind the action; the action is instead the agent. Rather, the ‘attracting’ or ‘drawing’ is the action articulating local states of a system in development. Some points in phase space are more metastable than others. So the system keeps shifting from one unstable state to another, until it encounters a metastable state –an attractor. It remains in that metastable state until a perturbation shifts it out of the attractor, and then it cycles through phase space again until a further metastable state is encountered. Thus, no ‘attraction’ as such by the ‘attractor’. For self-organising systems, the notion of *more favourable* can be replaced with *more stable* or *with more potential for growth*. Nevertheless, the dynamics implicit in an adaptive landscape, commonly do not lead to the most adaptiveness state: the system has no option but to go by the way of the steepest descent. Usually, this way will end in a local minimum of the potential, not in the global minimum. The only way to release the system out of a local minimum is to add a degree of indeterminism to the dynamics, that is, to enable the system to have the ability to make transitions to states other than the locally most adaptative one. This can be understood as the introduction of “noise” or random perturbations into the system, causing a deviation from its preferred trajectory. Physically, this is what commonly occurs with external perturbations. Such perturbations can drive the system towards a higher potential. This may be enough to let the system escape from a local minimum, after which it will again start to descend towards a possibly deeper level. The more intense the noise, the greater the ability of the system to exit potentially deeper levels. This shows how all non-equilibrium processes are to some extent stochastic.

Thanks to examples like the technique of “annealing” in metallurgy, where the gradual reduction of temperature favours the piece obtaining a greater hardness, allowing the metal molecules to settle in the most stable crystalline configuration. A random perturbation (an injection of energy from outside the system) can propel the system into an attractor state at a higher energy level than the original state. The point is, that the system, thereby, ‘avoids’ entropy by means of ‘noise’.

In the words of Deleuze and Guattari, we can think of the previous example of the annealing technique as noise-induced order in the operation of metallurgic individuation of matter: “What metal and metallurgy bring to light is a life proper to matter, a vital state of matter as such, a material vitalism that doubtless exists everywhere but is ordinarily hidden or covered, rendered unrecognisable, dissociated by hylomorphic model” (2005: 411). Random unbiased noise can appear in an organising agent that generates order where there is none in its absence (Wio and Lindenberg, 2003). Hence, noise becomes a vital element of the dynamical evolution of the system. It needs to be pointed out that such a productive role of noise is only possible in nonlinear non-equilibrium systems and is exclusively the result of the complex interplay of noise and nonlinearity in states away from equilibrium, that is to say: *in metastable equilibrium*. Because otherwise: “[a]t equilibrium all possible transformations have been actualized and no force exits. When all potentials are actualized, system having reached its lowest energy level can no longer transform itself ” (Simondon, 1995: 6).

A theory of metastabilities or “the theory of operations” (Simondon 1992: 261; 2005: 559) would describe the relation between structure and operation, and the internal processes which take place during an operation of individuation. This theory of changes to a structure in an operation, and vice versa, is called “allagmatics” by Simondon at the end of ILFI. From an allagmatic perspective we would be able to account for the blind spots that are productive in the aforementioned “ordinarily hidden” vital state of matter mentioned by Deleuze and Guattari. Yuk Hui explains in detail:

> Allagmatic, which is at the heart of philosophical intuition, seeks a genesis. But what exactly is this ground that Simondon is talking about? […] We associate the ground with a cosmic reality, but this cosmic reality, as the “becoming” of the “known being,” carries in itself something unknowable. It is the Unknown and the most contingent. […] Simondon’s philosophical intuition is that which produces a coupling between sensible and intellectual intuition (if we assume that it exists and is accessible to human beings, as it is argued by philosophers after Kant: for example, Fichte, Schelling, and Mou Zongsan (2019: 228)

What is this “cosmic reality, as the “becoming” of the “known being,”” (ibid.) if not the corroboration that “all starmaking, we might say, occurs within nebulae” (Grant, 2020: 9)? This unambiguously brings to mind the very idea of the connection between genesis and noise, an origin that is itself unknown[125]: what I will call *noxiogenesis*[126]. Noise is the

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[125] OED from the second edition (1989): noise, *n.*(nɔɪz) Forms: 3–7 noyse, 4–6 noys, 5–6 noyes, *Sc.* noyis, 6 noyse; 4 nois, 6 noiz, 3– noise. Also 4 nouse, nowse, 5 nose. [a. F. *noise* (11th cent.; OF. also *noyse*, *nose*) = Prov. *noysa*, *nosa*, *nausa*, of uncertain origin: L. *nausea* and *noxia* have been proposed, but the sense of the word is against both suggestions.]

[126] Noxĭus, a, um, adj. (I comp. noxior, Sen. Clem. 1, 13, 2 dub.; al. obnoxior.—Sup. noxissimus or noxiissimus, Sen. Clem. 1, 26, 3 dub.; better, noxiosissimus) [id.]. I *Hurtful, harmful, injurious, noxious* (used by Cic. only in archaic lang.; v. the foll.): MAGISTRATVS NECOBEDIENTEM ET NOXIVM CIVEM MVLTA COERCETO, Cic. Leg. 3, 3, 6 (araneus) aculeo noxius, Plin. 9, 48, 72, § 155: afflatus maris (opp.

ontological condition of morphogenesis –rather than the antithesis of order, as it appears in information theory and thermodynamics etc. In the beginning, stars were few and noxious gases were plenty. I propose this notion of noxiogenesis where the actuality, the reality for both stars and humans, emerges from refined discrimination (*i.e.* from learned capacity to involve complex discriminations in our judgements, whether they be aesthetic, logical or mathematic), that ability to learn and to bring these things to experience is developed against the backdrop of an indiscriminated whole which is nevertheless part of *the* noise. Part of the noise which is the background out of which actuality emerges. Hui continues:

> [the] Unknown can never be known objectively, since when it is known it is no longer unknown and so no longer remains the absent other of the system, but rather becomes part of techno-science. We must emphasize that the Unknown is an epistemological category, not the mysterious ineffable thus named out of mere "laziness" or "irrationality." If we put the divine, the Unknown, absolute contingency, incalculability, and even Dao into this category, it is not simply a gesture to affirm the irreducibility of life to physico-chemical activities, or of spirituality to matter, but also to suggest that it is necessary to *rationalize* the Unknown […] (2019; 229)

We can continue framing this under the perspective of what Goodman (1978) understands as syncategorematic. A term has a syncategorematic meaning just when the meaning arises by contrast, we never have the final meaning of a term or the final form of an idea, the world is never finished in its makings, rather they are only discriminable individuatable moments in the world's journey where it seems to acquire specificity of form but the conditions of specificity of form is that it contrast with 'alien' forms. Goodman's syncategorematic nominalism entails that all individuation occurs by differentiation. Individuation thus involves a functional space of plurality, a collation of aliens, without which it could not occur. The pluralism of the symbolic generation of words, as proposed by Goodman (ibid.) helps us to understand Simondon's conception of system formation via technical devices. Under that perspective, technology can no longer be understood simply as applied science, as the practical result of purely logo-theoretical work, as an application of a logocentric interpretation of the world, or as an instrument that falls in *hypertely*. "Hypertelia", strictly speaking, designates "functional over-adaptation" (Simondon 2017: 53), overdetermination to a single function of technical objects. In such a case, a machine might be attuned to very

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utiles), id. 17, 4, 2, § 24: tela, Ov. Tr. 5, 10, 22: terrae halitus, Quint. 7, 2, 3: lingua, Mart. 2, 61, 7: aves, rapacious, id. 10, 5, 12: crimina, Verg. A. 7, 326. — . In: Charlton T. Lewis; Charles Short (1879), *A Latin Dictionary; Founded on Andrews' edition of Freund's Latin dictionary.* Oxford: Trustees of Tufts University.

particular conditions of operation and lose a degree of functionality, and accordingly ‘autonomy’, outside their particular field of operation. Hypertelic technical objects are ‘closed objects’, in that they do not orient themselves “to being continued, completed, perfected, extended’ (Simondon 2012: 13). Technology cannot be reduced to a utilitarian function; technology must be understood as an *ensemble*. The technical ensemble does not have an “associated milieu:” It is a group of machines that operate conjointly as a result of human organization. The “technical ensemble”, as a system, itself inhabits a phase space. Its dynamic, then, is to respond to perturbation by random movement through state space (adaptation), until it encounters further adaptive metastable states. The “attractor” does not, actually ‘attract’ –thus, as Simondon says: “[t]echnical objects are free in their evolution and not pushed by necessity in the direction of a fatal hypertely” (Simondon, 2017: 58).

Simondon’s concepts of individuation and transduction intersect with this technological problematic through his critique of the ‘hylomorphic’ distinction between matter and form. The theory of individuation through transduction in a metastable environment understands individuation as genesis, encompassing the differentiation between individuals: the individual is for him an effect of individuation rather than a cause. His philosophy stands out as a harsh critique of the ontological privilege given to the constituted individual being (as a final equilibrium) in regards to its unity, as proposed by substantialism and by the Aristotelian hylemorphic schema. Hyleomorphism (which is opposed to atomist substantialism) tries to account for the genesis of the individual, conceiving being (*ousia*) or the individual as engendered by matter and form. This is deficient when it comes to fundamental genesis, because in this case, matter and form pre-exist their union. In this coming together it is as an imposition upon inert matter of a pre-given abstract form. Hylomorphism fails to account for the genesis of form (morphogenesis) and so does not ‘include’ any account of energy, metastability, and information. Ontogenesis is a synonym of individuation: “individuation is thus considered as the only operation that is truly ontogenetic, as the operation of complete being” (Simondon, 2005: 25, my translation) since the individual atom is replaced by an endless ontogenetic process of individuation. Individuation stands for the onto-genetic emergence of form or, as we will see, of *information*. We can contrast here two senses of “ontogenesis”, roughly corresponding to the two senses in which “morphogenesis” is taken: 1) the biologists’ sense of the production of individuals, as opposed to phylogenesis (this idea clearly informs Simondon’s version); 2) the philosophers’ sense of the *genesis of being* (Plato, *Philebus*, 26d), as opposed to the ‘fall’ of becoming from being (Augustine) or the sheer *being* of what just *is* (Parmenides, Aristotle). It is on the basis of this contrast, for instance, that ontogenesis can be considered synonymous with individuation.

We can establish a solid bridge between Simondon's philosophy and self-organisation by recognising that individuation stands for the process of phase transition. We have already mentioned the crystal growth as a first-order phase transition, and for Simondon, crystallisation is the perfect example of individuation: a supersaturated solution is metastable. From that pre-individuated field, surcharged with gradients of density that are only implicit *forms* or *potential functions*, individual crystals precipitate out. These crystal growths being pathways through phase space from the metastable supersaturated solution, to other metastable destinations involving part or entire crystallisations from the solution. The solution is inhabited by many potential/virtual (in Deleuze's terms[127]) routes of crystal individuation. Some will be actualised, others not, but all are 'real'. In other words, all crystallization processes share the same virtual structure even as they are singular individuations or actualisations of that structure. Individuation addresses the process by which intensity is demonstrated in qualitative extensity and clarifies why intensity does not stay within itself.

The version that Simondon offers us regarding the operation of the brick production reveals the essential elements of his theory of physical individuation; the genesis of the physical individual is the result of a mediation between two heterogeneous orders of magnitude, one that is above the individual and the other below it:

> The principle of individuation of brick is not the clay, nor the mold: this heap of clay and this mold will leave other bricks than this one, each one having its own haecceity, but it is the operation by which the clay, at a given time, in an energy system which included the finest details of the mold as the smallest components of this wet dirt took form, under such pressure, thus left again, thus diffused, thus self-actualized: a moment ago when the energy was thoroughly transmitted in all directions from each molecule to all the others, from the clay to the walls and the walls to the clay: the

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[127] It is due to the emergentist influence of Henri Bergson that Deleuze states:

> The virtual is not opposed to the real but to the actual. The virtual is fully real in so far as it is virtual. [...] Indeed, the virtual must be defined as strictly a part of the real object as though the object had one part of itself in the virtual into which it is plunged as though into an objective dimension. [...] The reality of the virtual consists of the differential elements and relations along with the singular points which correspond to them. The reality of the virtual is structure. We must avoid giving the elements and relations that form a structure an actuality which they do not have, and withdrawing from them a reality which they have. (1994, 208-209)

> principle of individuation is the operation that carries out an energy exchange between the matter and the form, until the unity leads to a state of equilibrium. (1964: 44)

The craftsman acts on materials (cast and clay) by means of interaction with the technical elements (workshop tools), and in which potential energy of the system individuation originally resides, generates a process of concretion:

1. Starting from the abstract geometric shape, and descending towards the concrete material cast.
2. In the lower order of magnitude, the work on the clay makes possible, thanks to the homogeneity achieved, an interactive communication between molecules, called by Simondon: "internal resonance".[128]

This communication is what enables the clay to momentarily convey the potential energy contained in the inter-elementary order; the cast establishes topological limits to the actualisation of this energy and the clay fills the cast uniformly through the intra-elementary communication of its molecules. Simondon replaced the Aristotelian *hyle* for a consideration of a set of material conditions that possess implicit forms and intrinsic aptitudes or arrangements[129]. Matter does not disappear as a condition for individuation; what disappears is the view (present in Aristotle and recurrent in the discussions between mechanists and vitalists) of inner matter needing an external principle to it, in order to organise and take shape. Matter is vitalised as a principle of production, necessary but not sufficient for the

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[128] To be fair to Aristotle, three of his four "causes" are included here (clay, cast, craftsman) while, arguably, the metastable "attractor" substitutes for his "final cause". It is possible that Aristotle was orienting himself towards an dynamic account of morphogenesis with hylomorphism - without having any of the thermodynamic or systems theoretical concepts we have today. Certainly, Thom considered this possibility. In his article: 'Aristote et l'avènement de la science moderne' (1991), exploring the relation between Aristotle and modern science, Thom states:

> I belong to those who think that the hylemorphic schema is still valid, because it is equivalent to the classifying role of concept in the verbal description of the world. [. . .] I am convinced that during the last years, in several disciplines, there appeared situations that can be explained by the presence of local fields or forms and that absolutely justify the old Aristotelian hylemorphic model, according to which nature is in some sense captured by form. Of course, I do not hide myself the fact that here, Aristotelian form, the "*eidos*", was a being that had nothing mathematical. It was an entity that carried its own "*energeia*", its activity, and it is clear that, for Aristotle, form did not have the status of a mathematical object that would have led him to a certain form of Platonism. The fact remains that the Aristotelian "eidos"has a certain efficient virtue which, anyway, one has to explain, and in the theories of modern science which I am alluding to, the efficiency of the "*eidos*" is expressed in mathematical terms, for instance using structural stability. (1991: 491ff)

[129] It is worth noting that potential forms and aptitudes are perfectly 'real' for Aristotle too.

possible individuations. With the form, we are witnessing a similar reform. The form descends from an abstract geometric consideration to a specific topological consideration[130]. While geometry organises physical points into a space, topology relates to the features of spaces under ongoing deformation[131]. Such deformations maintain characteristics like the "connexion" between two points in a space but not particularities like the distance between them. As the matter has form, the form must be materialised to have a real effectiveness. Therefore, it is no longer possible to conceive matter and form with an asymmetric relationship in which the latter plays a preponderant and active role. What we understand as matter, has form implicit as part of its constitution as matter (the metastable states it can take up as a system, its internal 'communications'). That is part of the very definition of matter for Simondon.

In order to establish a link between Simondon's theory of individuation and the behaviour exhibited by self-organising systems, it is interesting to see how Simondon perceives a living system. The unity of being, Simondon tells us, is "transductive", not only as a "system of individuation" but also a "system that individuates itself" (Simondon, 1992: 305); there is a dynamic interrelation between the constituted entity (individual) and the constituting process, which is itself one of (continuous) individuation. Simondon details his idea:

> The living entity is both the agent and the theater of individuation: its becoming represents a permanent individuation or rather a series of approaches to individuation progressing from one state of metastability to another. The individual is thus no longer either a substance or a simple part of the collectivity. The collective unit provides the resolution of the individual problematic, which means that the basis of the collective reality already forms a part of the individual in the form of the preindividual reality, which remains associated with the individual reality. (Simondon, 1992: 307)

We can say that when a system individuates itself it is in the path of transition from one metastable state to another. The process of continuous becoming wherein transient states of metastability are accomplished is called by Simondon a "metastable transductive unity" (1992). A being possessing a transductive unity, expresses the possibility of dephasing itself in relation to itself: "it can overflow out if itself from one part to another, beginning from its

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[130] Having said this, it must be clarified that Aristotle recognises the need of some principle of organisation, even though we can see in his work that there is a sense in which matter and organisation are external to one another.

[131] "All worlds bear these two spatial articulations – structural (topos) and geometric (locus)" (Bawa-Cavia and Reed, 2020: 85)

center" (2009: 11). We can think of reality as the never-ending transit of the "phasing" of being in and out of phase, each becoming, transformation, inception and expiration of being is an *assemblage* of these phasings or becomings. Tim Maudlin expresses it in slightly different terms: "[n]o serious realist would want to fix "once and for all" the entities which are to be considered real" (1997: 19). There is a succession of transductive phase-changes, since each rearrangement of the system provides the starting-point for a new transformation. Information is the transition of being which is dephased and which becomes: it is "the seed around which a new individuation will be able to be achieved", and constitutes the transductivity of different phases of individuation (1964: 241). But we should ask ourselves about the problems of a presupposed unity that "seed" seeks to account for. The metaphor of the seed is problematic insofar as what it makes a seed a seed? its inherent seed-hood or the pre-individual field that individuates it? Is that field then the seed of the seed or, if *genuinely* pre-individual, the seed's emergence cannot be due to *any seed*. This is expressed in better terms by Grant:

> "Everything is primal germ" now states both that if there is emergence, there is only one case in which emergence does not occur: the case of nothing; and, if there is emergence anywhere, it is maximally non-local. Every exhibition of the universal exhibits the universe in a universe, but the exhibited universe is itself a morphogenetic instance. (2015: 123)

Visibly, transduction is a theory of self-organisation both in its reference to stability and metastability and the emergence of structure in a process of relaxing a system of tensions or intensities– the differences that drive structural and state changes in a system. In this context, when we talk about "emergence", we are talking about the appearance of a property or feature in a system, not previously seen or that is not contained within any of the other parts. As Crutchfield (1994) said: "the whole is greater than the sum of the parts", emergence is the process under which larger patterns, beings or matter arise through interactions among smaller or less sophisticated entities that themselves do not show such properties. There must be an interplay of order and randomness. Through this *frictional 'quarrel' of interactions*, noise plays its role as ontological condition of morphogenesis. Complexity is the result of this 'balance' so that we can achieve genuinely new information arising from a 'structureless' universe (Crutchfield, 2002).

Individuation will continue taking place as long as the system has not attained a final stability and exhausted its potential for change. In fact, if we want to be rigorous, final stability is a kind of "idealised state", since it requires a closed system that does not interact with its surroundings, or is not distinct from them (thermodynamic equilibrium). Open systems that sustain at least some range from equilibrium, or, are far from equilibrium like living organisms and ecosystems, can be regarded as continuously individuating. Transduction, however, goes further than the formal comprehension of self-organisation in addressing complex scenarios that are more complicated to represent in terms of information or energy exchanges. While self-organisation[132] usually characterises the convergence of trajectories towards attractors within an already configured state-space, transduction does not presuppose such a priori arrangement that is distinctive only to already individuated systems. Transduction (like noise) establishes an ontogenetic and relational process through which a 'sphere' of being finds in another its principle of constitution. The transductive movement presents no principle, rather, it draws 'solutions' out from regions in 'friction'.

The ferocious critique posed by Ray Brassier: "[t]he fetishizing of complexity in the sense of self-organization, along with emergence and irreducibility, etc., is part and parcel of the neo-vitalist tendency to prefer mystification to explanation, so prevalent today." (2009) is not unjustified. The popular belief that the natural world is composed of self-regulating ecosystems that tend towards balance and equilibrium penetrated deep into the public imagination during the second half of the 20th Century. A fantasy of machine-like stability. The problem is that, as many ecologists have shown, this is not true and nature is never stable, it is always changing. While a self-organising system is good at organising change, it fails to provide a "meaning" for determining what comes next in time. Brassier considers noise interesting, precisely because of its "dis-organizing potency": the incompressibility of a signal interfering with the redundancy in the structure of the receiver. Not transduction but schizduction: noise scrambles the capacity for self-organization" (ibid.). But I must disagree[133] and appeal instead to noise's capacity to trigger and impel continuous processes

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[132] Even though thinkers like Kauffman certainly do describe pathways through 'A' state/phase space, as though it were a static fixture (1995, 1996, 2000). We can see this just as an analytical convenience. Self-organisation theorists are perfectly aware that since all systems are really open systems, the state/phase space must, itself, be plastic. Self-organization is facilitated by random perturbations (noise) that let the system explore a variety of states in its state space. Simondon and contemporary self-organisation theorists would then be complementary.

[133] My critique can be extended to Wilkins' (2021) attack on fetishisation of self-organising systems and exaltation of chance. There is nothing fetishistic about complex systems science - it is well respected from fluid dynamics, to population science, to machine learning. It is used, precisely, to 'explain' things.

of *re-organisation* in a radical constructivist way (Noë, 2015). We are compelled to make sense of those perturbations, of the signal that is not accommodated within the redundancy of the predictions modelled by our perception, of the statistical irregularities of the world.

3.4: Pre-individual: potential for emergence and organisation

> [T]he individual is to be understood as having a relative reality, occupying only a certain phase of the whole being in question – a phase that therefore carries the implication of a preceding pre-individual state, and that, even the single act of its appearance all the potentials embedded in the pre-individual state. Individuation, moreover, not only brings the individual to light but also the individual-milieu dyad. (Simondon, 1992: 300)

Despite having already outlined some of the ideas through which we can understand the pre-individual as a material level of relations out of which the individual emerges throughout a process of individuation. I think it is necessary to provide some remarks.

Simondon's quote above highlights path dependency and irreversibility. As the system takes one route through its phase space, it simultaneously excludes other possible routes –for ever. Real - potential worlds that never become actual. The system cannot go backwards through phase space (since that would, literally, involve a reversal of time) and so a cosmic reduction in entropy. It can only get to certain "adjacent possibles" as Stuart Kauffman (1996, 2000) calls them, from its current metastable state –and its current state is determined by its prior path. This power of the past in delimiting the present "adjacent possible", and the carving out of an "actual" path from a pre-individual field or phase space.

Everything has its origin in the "preindividual field". Simondon establishes that the first attribute of the pre-individual is that it is distributed according to different "orders of magnitude" (2005: 31–32, my translation). The pre-individual is not static or inert but fundamentally dynamic, far from being a state devoid of unity or identity the pre-individual is a condition that "before individuation, can be grasped as more than a unity and more than an identity"[134] (2005: 32). Simondon draws the pre-individual notion from the theory of thermodynamic metastability and the account of wave-particle duality in quantum mechanics.

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[134] Precisely the same as Deleuze's reversal of identity and difference (Deleuze, 2004)

This duality is “more than one” and in so far as the particle is, expressly, not an individual, but, instead, a probabilistic pre-individual field. Simondon declines fixed entities in a clear confirmation of the dialectical character of his philosophy: the pre-individual will set up a system of relations steering the genesis of the individual, but only in so far as the individual, in its emergence, actualises or structures these relations. The pre-individual operates as a field of potentials full of tensions, full of dissonances, full of *noise*. As Muriel Combes states: “The emergence of an individual within pre-individual being should be conceived in terms of the resolution of a tension between potentials belonging to previously separated orders of magnitude” (2012: 4). Each individual movement in the coordinated movements of a school of fish, for example can be understood as mediating (or resolving the tension) between the fixed set of swimming rules (how sensory signals from the eyes and the lateral lines are interpreted by the fish) and the maintenance of certain distance from every neighbour, obstacle or predator[135]. Combes continues: “… we may consider individuals as beings that come into existence as so many partial solutions to so many problems of incompatibility between separate levels of being.” (ibid.) An individual is not only a consequence but also an operator of individuation because it maintains a relation to its correspondent milieu which means that it conveys a consignment of pre-individual potentialities; in other words, a living being is an open system with a tension tangled by the presence of potentials, this tension is the so-called “internal resonance”.

Simondon stated that the inner dynamics of his theory of individuation cannot be studied coherently under the approaches of either determinism or pure indeterminism.

> Determinism and indeterminism are just borderline cases; because there is a development of systems: this development is the one of their individuation: there is a reactivity of the systems in relation to themselves. The evolution of a system would be determined only if there was not an internal resonance of the system, that is to say no exchange between the different levels which are held within it and by which it is composed; in this case, no quantum exchange would be possible and you could know the development of this system thanks to a theory of the continuous, or thanks to the law of large numbers, such as in the case of Thermodynamic theory. Pure indeterminism would coincide to a huge internal resonance, thanks to which every modification

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[135] It is worth asking, in view of these strategic responses to predators, feeding/nutrients etc. whether the school of fish is, itself, an individual. So called ’superorganisms’, social insect colonies, etc.are routinely conceived as collective individuals, rather than collections of individuals. The fact that there are no clear answers to such questions, we take as evidence of the constant emergence and submersion of the individual in pre-individual fields. Suzanne Langer refers to this dialectical dynamic as “individuation and involvement” (1967, 1972, 1982).

> arriving on a determined level would immediately reverberate on every level disguised as a change of structure. (Simondon, 2005: 148–149, my translation.)

Subsequently, pre-individual nature connected with the living being is exactly what opens the door to forthcoming individuations. “The individual is invaded by the pre-individual: all of its structures are attacked, its functions animated by a new force which renders them incoherent” (Simondon, 2005: 256, my translation). Noise *percolates*[136] all individual and collective structures. This removes nodes from networks, *propels* fragmentation that goes from biological virus shells[137] to human communication. It ‘animates’ our cognition in a cascade of downwards flowing prediction processes to accommodate sensory data (Clark, 2015), helping the brain to integrate “distributed and specialized networks into a coherent information processing system” (Del Ferraro et al., 2018: 2)

Transduction, for its part, is meant to take place when two systems which are initially discordant come to interact with each other. Simondon uses two notions to explain this incompatibility or unresolved tensions: the first is the already mentioned term “disparity” which stands for two elements that initially do not share any common ground. The second notion is “problematic” in the sense that two systems assert a problem to each other that requires some resolution. For example: the problem the environment asserts to an organism which requires it to either adapt or change the environment. The resulting interplay is a transductive process that conducts the individuation of both organism and environment. In the process of their interactions, the consequences of which are firstly undetermined, they form certain relations of resonance or correlative determination by one inhibiting the dynamics of the other. When such a process reaches a relative stability an organisation or a structural pattern emerges as the individual. Both original systems have changed and they now exhibit a pattern of (more or less) regulated interaction that also evidences a manifest boundary[138]. Nevertheless, the resolution is never terminated. The remaining unsolved features of the interaction are those that preserve the pre-individual being within the formed individual and will (at some point) induce further individuation –since there can be no ‘final’ solution.

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[136] Percolation is a simple probabilistic model for spatial disorder –removal of nodes from a network. It has various applications: random growth models (sand-pile models), communication networks, Markov decision processes, etc. See: Grimmett, G. (1999) *Percolation*. Berlin Heidelberg: Springer.

[137] see: Brunk, N.E., Lee, L.S., Glazier, J.A., Butske, W. and Zlotnick, A. (2018) Molecular Jenga: the percolation phase transition (collapse) in virus capsids. *Physical Biology*. 15, 5.

[138] Again, this resonates with Susanne Langer's individuation and involvement.

3.5: Conclusion

We have now set up a series of contrasting conceptions of ‘noise’. The thermodynamic and information theoretical noise is a ‘creature’[139] of neg-information (entropy). The ‘enemy’ of the ordered form, information. The noise presented in this chapter, the pre-individual, is a ‘creature’ of negentropy –of morphogenesis. It is the pure-difference (in Deleuzian terms) that is a precondition for any ordered process of individuation to emerge in the first place. It is the far from equilibrium environment out of which metastable temporary ‘solutions’ can emerge as the system transitions through the pre-individual state space.

Simondon’s philosophical insight concerning individuation processes makes clear that the potential of noise is never-ceasing, as individuation is itself never-ending, and this is assured by the pre-individual nature of metastability. Also, noise, as well as information, are beyond the ideas of information as content submission as in the classical cybernetic model of information transmission. Noise is metastasised[140] from the register of determinacy towards indeterminacy, exhibiting the *plasticity* of morphogenesis, it names the potential of the system to have its initial determination transformed indefinitely. The metastable nature explains why “the piece of information acts in fact as an instigation to individuation, a necessity to individuate” (Simondon, 1992: 311), making the process of individuation and the individual one and the same thing. Thus, noxiogenesis is the irresoluble proccess of frictional and refined discrimination, origin of *all* negentropic forms.

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[139] Thanks to Sean Watson for inspiring the characterisation of noise as ‘creature’.

[140] To be changed or transformed.

Chapter 4: Conjuring Chance: Digital Omens and Platforms of Prediction

> All stable processes we shall predict. All unstable processes we shall control.
>
> John von Neumann
> (Dyson, 1988: 182)

> [[ ]] An explosion of chaotic weather within synthetic problem-solving rips through the last dreams of top-down prediction and control. Knowledge adds to the mess, and this is merely exponentiated by knowing what it does.
>
> [[ ]] Capital is machinc (non-instrumental) globalization-miniaturization scaling dilation: an automatizing nihilist vortex, neutralizing all values through commensuration to digitized commerce, and driving a migration from despotic command to cyber-sensitive control: from status and meaning to money and information. (2011: 444)
>
> Nick Land
> *Meltdown*

4.1: Introduction to the Chapter

Humankind has been reading messages in random patterns since prehistoric times[141]. But since the 1940s, chance came to operate (through the employment of randomness) in domains such as systems theory, mathematical modelling and advanced methods of strategic planning.

In the 1940s and ’50s, in research groups during World War II, and subsequently, in the large-scale military engineering initiatives of the Cold War, a new arrangement of chance-procedures became indispensable for the new emerging fields. From that moment onwards, high-quality (pseudo) random numbers[142] have been essential for (among other things) cryptography, climate modelling or nuclear weapon design (Hayes, 2008). All these exemplify how contemporary prediction technologies are dramatically transforming our relationship with the future and with uncertainty in a great number of our social structures.

But how is this method of forecast different from, or comparable to primitive ritualistic techniques of divination?

For us, today, forecasting is one of the main objectives of science. Karl Popper’s *Conjectures and Refutations* (1963) and *Objective Knowledge* (1972) both contain discussions of the topic, and are concerned to demonstrate that a theory is scientific when testable, i.e. when it predicts certain outcomes. Conventionally, this entails the formulation and solution of the mathematical equations and models, describing the past and future behaviour of a process within the boundaries of the system at issue. When this approach turns out to be unfeasible, we generally engage in stochastic methods. Here, the notion of “stochastic” comprises a wide range of techniques that are supported by the employment of unpredictable units (random numbers) to make predictions practicable. There is a significant difference between science,

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[141] Sheynin, O. (1974). On the Prehistory of the Theory of Probability. *Archive for History of Exact Sciences,* 12, 2. pp. 97-141.

[142] It is interesting to pay attention to the publication of *A Million Random Digits with 100,000 Normal Deviates*, originally published in 1955 by RAND Corporation. Consisting primarily of tables of random digits. The tables were designed to be used in mathematical and scientific experiments particularly in the area of cryptography.

which is mainly concerned with *explanandum*[143]: *why* something occurs, and divination and predictive analytics that on the contrary, are concentrated on the "what". The latter two are conjured in reaction to a particular reality, do not, primarily, attempt to comprehend *how* or *why* it has occurred, but merely to predict its potential occurrence. Both procedures share the objective of providing a prediction which can be coordinated with the algorithmic or 'cosmic order', and contribute to a future which streamlines the use of accessible means. In the past, this may have been done in order to gain insight about an impending voyage. Nowadays, it may be in order to prevent global pandemics. But again, human culture has negotiated with chance from the very beginning. Different methods of prophesying have assisted us as 'buffers' between human communities and their environments for thousands of years, using divination for agricultural activity, as navigational orienteering techniques, advice before going to the battlefield, etc. These were techniques developed by human groups in order to address our shared uncertainty about the future[144].

> [S]ociety as a whole becomes expectant and obsessed by the rite—we find the same feeling in our own culture, particularly among huntsmen, fishermen or gamblers, all well known for their superstitions. The collecting together of this kind of committed group provides a mental atmosphere where erroneous perceptions may flourish and illusions spread like wildfire; miracles occur in this milieu as a matter of course. The members of such communities are experimenters, who have accumulated a myriad opportunities for error. They are in a state of perpetual aberration, where at any moment a chance event will be proclaimed law, a coincidence a rule. (Mauss, 1972: 162-163)

As we are seeing, randomness is an unavoidable element in divination. Every rite begins with the examination of a fortuitous event, such as the movement of crabs in the practise of Nggàm[145]. Divination is, in fact, one of the most common human activities intrinsically connected with randomness[146]. With the point, in divination, being to trace the order emergent from randomness. The patterns in the sacrificed animals spilt intestines, messages

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[143] See: Hempel C.G. and Oppenheim, P. (1948). Studies in the Logic of Explanation. *Philosophy of Science*. XV, 2. pp. 135–175.

[144] With terms like "prophecy" and "divination" we are not implying that all pre-scientific forms of prediction and forecasting were entirely without grounding in reason and practical experience. This obviously is not the case. Prediction of forthcoming weather patterns based on patterns of plant growth, animal migrations etc –were not "prophetic" or "divinatory" as we generally understand it. Use of natural remedies were often effective, and again rooted in empirical experience rather than mystical belief.

[145] See: Zeitlyn, D. (1987) Mambila Divination. *Cambridge Anthropology*. 12, 1. pp. 21-51.

[146] See: Peter Struck addresses these in the context of ancient philosophy, but calls divination a piece of "surplus knowledge". See: Struck, P.T. (2016) *Divination and Human Nature*. Princeton and Oxford: Princeton University Press.

emergent from the babbling voice of the oracle. Such patterns being conceived as messages from ‘divine’ origins. The ancient communities of Eurasia, and posteriorly of North America, performed divinatory practices to guide hunting expeditions towards areas where the animals might be found. These rites had a huge relevance, since the recurrent failure of hunts might have resulted in disappearance of a population. Naskapi Indians practised the “scapulimancy”, they hold bones over a fire until they crack and then hunt in the directions to which the bones crack. O.K. Moore’s words about their patternless hunting techniques and their rate of success is noteworthy:

> If it may be assumed that there is some interplay between the animals [the hunters] seek and the hunts they undertake [....] then there may be a marked advantage in avoiding a fixed pattern in hunting. Unwitting regularities in behavior provide a basis for anticipatory response. For instance, animals that are “overhunted” are likely to become sensitized to human beings and hence quick to take evasion actions. Because the occurrence of cracks and spots in the shoulder blade and the distribution of game are in all likelihood independent events, i.e., the former is unrelated to the outcome of past hunts, it would seem that a certain amount of irregularity would be introduced into the Naskapi hunting patterns by this mechanism. (1957: 71)

When deciding to take a random path, the hunters might be directed by the insight of the diviner by more than simply his access to the supernatural world. In order to take advantage of chance, mathematicians and computer scientists search for a probably correct result in a certainly short time (Monte Carlo methods); or a certainly correct result in a probably short time (Las Vegas algorithm); or aspire at the increasingly complex goal of achieving a probably correct result in a probably short time, as seen in the peer-to-peer file sharing protocol (Kobsa, Nierstrasz and Weikum, 2011). The Naskapi hunting techniques succeed in performing this last method much earlier than the dawn of computation. The difference being, though, that the Naskapi are not aware that it is the randomness itself that is functional in increasing the likelihood of success in hunting. They believe, presumably, that the bones really do convey messages, of divine origin, that enable forecasting.

In this chapter, I aim to problematize the relationship between computation and the cluster of ideas that connect randomness and divination, by suggesting the allegory of predictive analytics as “devices of divination”. By doing this I am stressing two ostensibly conflicting elements of predictive analytics as a type of knowledge production: it is involved in the modest task of ordering data, but also professes to being able to unveil patterns only visible for ‘God’s eye’, the ‘hidden code’ of the ‘supreme designer’. On the one hand, data-driven analytics are mainly classificatory operations, designed to systematically identify, classify, and index uniformities among apparently independent items. On the other hand, these systems are conceived in both, the popular and the technical imaginary as prophetic devices (McFedries, 2017; Romeike and Eicher, 2016; Baker and Gourlet, 2015) that, like the omen for the seer, are able to provide access to *a* knowledge that surpasses the constraints of humans' faculties. I consider it is extremely relevant to pay attention to the way in which these two domains (divination and data analytics) present similar operations, since, as I will argue, what is at stake is the extent to which relying on algorithmic prediction as a form of knowledge-production falls in the same supposed non-rational, mysterious and even esoteric forms of dangerous ingenuity that discredited indeterminacy and chance processes; testimony to the coexistence and coevolution throughout the millennia of human and non-human intelligences.

This chapter will investigate the present-day 'faith' in the predictive capacity of algorithms by offering a double-edged interpretation and contextualization. Firstly, by examining the ontological aspect of divination practices viewed in parallel with predictive analytics and explore how these configure the world by enacting the presence of the future in the present time. Does our being remain the same if we receive the prognosis of a fatal disease? or after being informed about a future inheritance? Divination transforms ontologically those who receive the 'omen'. Reinforcing them onto a path on which the outcome of the prediction is newly integral. I consider this equivalent to the reversal of the direction of entropy that Wiener (1950: 24-5) identifies as the objective of the mechanisms of control of cybernetic systems. But if such divination is the tracing out of the features of the 'inevitable' in the present (and adjusting the world to that 'inevitable') is not that an aid to entropy? An oiling of the path of the universe towards its 'inevitable' fate –and ours. Digital divination and cybernetic aims are precisely this frictionless control nihilism. We do *need* to create unlikely futures in order to evade entropy. The entire divination of the future in the present, arguably, destroys the future –and, according to Stiegler (2019), thereby sends us mad.

For this reason, I will examine time as a central component of prediction, incessantly driving the (present) production of the future.

It seems, nowadays, as if, in light of the predictive power of algorithms, we are asked to reformulate once again the epistemological and ontological series of antagonistic dualisms: ancient and modern, analogic and causal reasoning, rational and irrational, we interrogate the irrational side of the construction of scientific knowledge and meaning, along with the pragmatic, immanently generative logic of non-scientific examples of worldbuilding. The appearance of this original kind of knowledge, puts into question the scientific grounds themselves, whose basic cornerstones have been the formation and testing of centuries-old hypotheses and theories. However, it is now generally recognized that data-driven sciences represent an additional cornerstone (NSF 2010) and this context generates numerous epistemological issues. This novel context poses a set of questions and concerns in different scientific fields and spheres of our world. When we pay attention to the narratives adjacent to predictive analytics it is remarkable to notice the extent to which these issues deeply reverberate the intense arguments connected with divinatory practices throughout history. This chapter will also assess the epistemological character of predictive technologies and review their hypothesis concerning the way in which they typify the future. The enterprise of predictive analytics, I maintain, have performed a central function in the formation of both the technical and conceptual profiles of a manifestly computational species of epistemology, one typified nowadays by the emergence of data mining, predictive modelling, machine learning, and any other relative computational methods comprising the techniques of statistical data processing that are established as mainstream methods of knowledge production.

Ultimately, this chapter promotes a philosophico-critical anthropology of data ontology; it highlights (just as the fetishism in Marx's account of its relation to commodities[147]) the fact of how often our construction of modernity has forgotten its anthropological roots. Yet these are important since they contribute an intimation, so to speak, of our modernity's primitivism in fetishizing this or that thing –data, sneakers, oil etc.. This offers a challenge to the algorithmic "microfundamentalism"[148] of our present, particularly that byproduct of pancomputationalism –as we will see in more detail in chapter 7.

4.2: A World Devoid of Chance?

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[147] See: Marx, K. *Capital Vol. I.* Section 4.

[148] Microfundamentalism recognises only elementary particles as real. In a narrow sense, this assumes that in reality there are no such things as books, cliffs or human bodies. See: Gabriel, M. (2015) Neutral Realism. *The Monist*, 98, 2. pp. 181–196.

A world that has been stripped of chance is not possible to interpret through chance: we require a very sophisticated and intricate method to escape from the world's meaning overload. Divination methods are based on procedures that in the same way as law or science (Bottéro 1974, 1987), need to break both the symmetry and the significant stability of a world where everything is in connexion with everything else. "There is thus no major discontinuity between primitive magical thoughts and modern scientific thought" (Thom, 1983: 136). As we mentioned in chapter 2, Marcel Mauss makes the same point in *A General Theory of Magic* (1972). However, for René Thom (as well as for us) there are two main differences between magic and science. The first is relative to the conventional way in which we perceive science as such. It is evident that science seeks the dreamlike goal of uncovering time-independent and universal facts. On the contrary, magic is concerned with local or individual issues –i.e. to ask the gods to perform an action on a person or object. For these reasons, we see how science transforms space-time into a universal vessel of all experience.

Technique is needed in order to insert chance into this world devoid of chance, or as Vernant (1974) suggested: to insert "game" into the system, and then, to create methods that experimentally expose the necessity in the order of things. Even when the outset is random, such as the rolling of dice while casting lots for tribal inheritance, or reading the flames of a fire, it is not an issue of researching the particular contingency at play or referring to the underlying causal process, but of staying at the *surface* to examine its conformation, its spatial arrangement. Deleuze wrote succinctly about divination in his argument of the event in Stoic philosophy. Divination is "the relation between the pure event (not yet actualized) and the depth of bodies, the corporeal actions and passions whence it results" (Deleuze, 1990: 163). In other words: divination paves the way for creation by searching in the emergent forms, the origin of forms that have not yet reached, of forthcoming actualisations and differentiations. This is the reason why in this section we need to reflect on the genealogical understanding of divination.

The analogy that it has been suggested: that science is a form of *divination*, is frequently relegated to considerations about the structural role these practices play within a particular society, operating as a sort of technology aiming at the control or understanding of nature. Discrediting non-rational belief systems, we could approximate ourselves to a characterisation focused on their logical operations of *prediction* and *sign*.

The central procedure related to all divination practices is the fortuitous association. That is to say, if event *a* correlates with sign *b*, then when *b* next shows up, *a* will occur. If we again withdraw the gods from the association then there is no direct connection between *b* and *a*. In other words, the "signs indicated events in a variety of ways, mostly by means of schematic symmetries, associations and analogy. The relationship between the sign (ittu) and its prediction (parassu) had no component of causation, nor necessity of any particular temporal relation, be it synchronistic or sequential" (Rochberg-Halton, 1998: 52). Despite the fact that the gods brought both the omen and the subsequent event, there was no causal inference between the two. Still, examples like oracle bones bear the earliest known significant corpus of ancient Chinese writing (Qiu, 2000), and the invention of the oracle would imply the beginning of science, as it introduces the question of *how* probabilities can be systematized in some form. It could be that the Chinese written language had its very origin with oracles attempting to circumvent fate, trying to suppress the *second law*'s restraints of time*,* in whose measure we are eternally doomed. The pledge of modern computation is that this capacity of divination is within everyone's reach at last. Computers enable us to master time, and hence in reading the future we will finally be capable of transforming it or cunningly evade its bumps –the goal of all prophets since the beginning of time. In fact, the binary number system (the basis for binary code underpinning computation) has its origin in the creative power of Gottfried Leibniz as synthesizer of ideas, who developed the notion after he encountered (through French Jesuit Joachim Bouvet) the most well-known form of Chinese divination text, the *I-Ching*[149]. The ambition to devise computing machines appeared with the Newtonian worldview and put into practice its premise*;* that is, that the world could be fully described in terms of equations whose outcome was predetermined. What computers pledged was the capacity and power to calculate these equations, granting us a power issued from asymmetric information. The manipulation of yarrow stalks, or the tossed coins for the *I Ching* divination, end up with the creation of an "experimental semiology" that produces and formalises its signs (bonded with augural formulas), detects correlations, mixes and interpolates them with each other to generate a divinatory algebra, from which follows a divinatory arithmetic –always aimed at addressing the meaning of the universe (Vandermeersch, 1974). The purpose is to incite the world to express itself, translating its structures in forms relevant to humans, more and more complex as the technique is evolving.

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[149] See: Leibniz, G. (1703) Explication de l'Arithmétique Binaire. *Mathematical Writings VII*, Gerhardt (ed). pp. 223-227.

The outcome is a “random mechanism intrinsically capable of learning” (Luhmann 1997: 237), all the more meaningful because the contingency of the beginning is subsumed into the higher necessity of the operation.

The primary logic of divinatory practices is based on necessity. When there is no linear cause-effect correlation and chance does not take place; the meaningfulness depends on the processes of analogies and interdependences between events and things, acknowledging the ordered structure of the universe (Vandermeersch 1974; Vernant 1974). It is under this perspective that all phenomena *surface*, and become visible as “signs of each other and not as consequences (or effects) of previous facts. In this sense divination is “the art of surfaces, lines, and singular points appearing on the surface” (Deleuze, 1990: 163). Each of these signs could in principle explain all the others and the links of progression turn into relationships of “symmetry” (Esposito, 2013: 130). These signs can be ‘registered’ in forces and matter of different sorts, from the patterns seen in rocks to the interpretation of the topography of the land or the examination of wind currents. They could be generated as well with the intention of receiving omens. This is the case described in Plato’s enchanting anatomical reflection about human nature presented in the *Timaeus*. Amongst the numerous obscure narrations found in the dialogue, it is reported that the soul has a sinister cast. The creators had to “bind this one down there like a wild beast” (κατέδησαν δὴ τὸ τοιοῦτον ἐνταῦθα ὡς θρέμμα ἄγριον) (70e). So considered, the liver[150] is seen as a ‘screen’ for images of rational ideas that are intended to scare the appetitive soul into submission, and, at the same time, function as a mirror for divinatory images. It is said that when the individual creature is alive this organ carries signs that are rather clear (τὸ τοιοῦτον σημεῖα ἐναργέστερα ἔχει) (72b), but when deprived of life it turns blind and the omens it exhibits are too obscure to signal anything clearly (τὰ μαντεῖα ἀμυδρότερα ἔσχεν τοῦ τι σαφὲς σημαίνειν) (72b). The language to which the organ responds is composed of εἴδωλα “phantoms” and φαντάσματα “visions,”. The liver functions as a mirror on which the highest part of the soul, confined in the head, can issue a corrective display. The correctives come from above in the form of “discursive thoughts” (διανοήματα) which the liver’s surface translates into the language that the lower soul comprehends. It assimilates impressions (τύποι) from above and mirrors back phantom images (εἴδωλα).

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[150] Hippocrates discusses such issues through diagnostic phenomena, as cited in Struck 2016: 1.

The challenge of the complex interaction between the *visible* and the *invisible* (that constructively represents the logic of divinatory activities) is now at the 'kernel' of the present 'faith' in the predictive capacity of algorithms. In this regard, it is relevant to note how the proponents of predictive analytics frequently 'conjure' wording of '(un)veiling' and '(in)visibility' to characterise the computations of algorithms. The purpose of algorithms is, therefore, to discover patterns in large data sets (data-mining) in order to 'reveal', from this second (digital) nature, important information ('visions') formerly hidden from us. The wording attests unequivocally the Graeco-Latin notion of "secrets of nature" (Hadot, 2004). The highly prevalent use of mine exploitation metaphors (data-mining) leaves nothing in question but the clear image that excavating beneath the surface of things can lead to 'hidden treasures'. Shared by both scientific and divinatory practices, this notion of nature's secrets is not, however, acknowledged in an equal manner. Indeed, if in both disciplines the goal is to reveal, to expose a 'hidden' reality, the reality to which divinatory acts relate is certainly different to the reality that the scientific activity determines. From the point of view of the divinatory practices, the reality that these methods try to reach is absolute, transcendental and endless, while the reality encountered by humans is no more than an impression, always incomplete and relative. Scientific practices (far from denoting an unobtainable and unutterable reality) "[...] are the result, on the contrary, of an empirico-mathematical confrontation where nothing is supposed to escape the quantitative discourse, i.e. determined by the conditions of measurement and measurability". (Atlan 1986: 120). Every scientific experiment is a question addressed to nature that nature is forced to answer. But every question contains hidden a priori judgement: every experiment qua experiment is prophecy: experimentation in itself is a production of the phenomenon. (SW III, 276 Schelling, 1858: 276). Divination is therefore a technique that does not recognize contingency for itself, because the premise is that any element of the world is regulated by a greater necessity. Nevertheless, it does not dismiss chance in itself, but contemplates it as a way of making the world capable of transmitting information that can be read by humans within their context, one of an environment governed by the sensitivity to initial conditions.

In Henri Atlan (2010), we find an enthralling example of how to understand (and politicise) the apparent modern loss of chance as oracular driving force in the rabbinic tradition. In other words, its cosmological, epistemological and metaphysical irrelevance in revealing the future. There are nevertheless times, when the exercise of randomness, performs an essential social function, enabling a social group to be cohesive by allowing a decision to be made or conflicts to be resolved when apparently, there is no possible solution through ordinary rational methods of deliberation. Atlan asks and expands on the role of chance:

> What role or roles may remain for the recourse to chance, such that we need to preserve it [in a post-prophetic, non-oracular age]? The example of the allocation of the land among the tribes is instructive, because it is discussed elsewhere in the Talmud. There we observe, though in another way, the same evolution from the sacred chance of divination to the conventional randomness of a world without oracles.
> [...] [T]he division of the land be effected "according to [*lit.* by the mouth of] the lot" [,][...]it designates a lottery that is mute and double-blind, with the names of the tribes inscribed on lots contained in one urn and the names of the territories in a second urn. [Is]"in this world" with another division of land, alluded to by Ezekiel (Ezekiel 48), that will take place "in the world to come." This second, eschatological division will repeat the original one; but this time it will be perfect, because all the territories will be identical in the wealth and diversity of their natural resources. Furthermore, this ultimate apportionment will be made by God himself: "those are their portions, the word of YHWH" (Ezek. 48:29). [...] [T]he first division "by mouth of the lot" is acceptable because it is temporary and affects only this world; but that of the future, eternal world will be made directly "by the mouth of YHWH." (2010: 198)

As we can see in this brief philosophico-anthropological analysis of chance's resistance to its own disappearance –along with the divinatory practices in the modern world - chance is conjured not as an *ultimate judge,* but as a method of progressing forwards in time when no other option is available. Nevertheless, the irony is that ruling out a quarrel via chance is actually the common acceptance of a non-resolution. This is to say, the imperative that no one knows the 'path of God' is made explicit in the repeated practise of non-oracular divinatory techniques, manifesting that indeed, no one had granted the whole (final) picture of the universe, so to speak. In other terms, we can see how the rabbis of the Talmud anticipate the contemporary, statistical 'naturalization' of chance (Atlan, 2010) from the manner in which they employ divination not in order to achieve a closing agreement on a dispute, certainly not to unveil a self-confirming, self-absolving, dissent-proof oracle, but rather to liberate themselves from the seduction of the false authority. We can think this in terms of system dynamics: when it is not possible to calculate the direction of the temporal evolution of a system by standard techniques, random numbers can be employed to produce an alternative evolution and facilitate its progress. They determine the probability distribution of the various possible directions. Departing from a possible arrangement, small, random changes are inserted to produce a new configuration: once this reaches a higher degree of stability, it substitutes the preceding one, generally until the most stable arrangement is found. Randomness is not able to tell us what the preferable direction is for the system to go in but enables the second-best solution: the navigation of the system-configurations while minimizing the influence of any bias that could disregard a region of possible solutions. If we are capable of estimating the probability distribution of the arrangements (rather than performing a uniform random search) we can conduct an "importance sampling" concentrating our exploration on finding the most likely location of the 'solution'. In the natural world, new genetic variations are brought about by mutations that occur randomly with respect to whether their effects are useful or not. But the best possible solution is not achieved for good and all. A constant dynamic environment entails that evolution is permanently shifting; it does not create the 'perfect' organism, on the contrary, it favours a dynamic range of countless organisms within an environment.

Back to rabbinic use of divination, we should have in mind the truly unknowable nature of ultimate reality (God's Mind). The rabbi then promotes divination when it can be exercised to adopt a stance of humility (ultimately scientific) in light of a reality that is not just complex in epistemic terms but ontologically unfinished: incomplete, inconclusive and activated by the "sparks of randomness." (ibid.)

> Casting lots or rolling dice no longer brings to light a hidden knowledge and the "correct" choice that stems from it, but only the partners agreement to the selection process despite its arbitrariness. The decision is not the result of knowledge that the oracle is held to reveal but of an agreement reached by convention, because we have no better way to decide in the absence of such knowledge. To put it another way, it is a makeshift to which we must consign ourselves when we have no other method to hand (Atlan, 2010: 293)

Nietzsche's own understanding of divination: "The power of understanding with only the least assistance, at the slightest suggestion, "intelligent" *sensuality* (Sinnlichkeit)" (KGW VIII 14 [117]) coincides with the ambition of governing randomness by technoscience that Emanuela Bianchi in *The Feminine Symptom* (2014) understands as an orchestration of chance for 'fated goals', for the goals of continually increasing control and prediction. Or as Ian Hacking states (1990), since the late nineteenth century, we have seen different attempts to tame chance "that is, of the way in which apparently chance or irregular events have been brought under the control of natural or social law […] Chance became tamed, in the sense that it became the very stuff of the fundamental processes of nature and of society" (1990:

10). That is how the world and society, by virtue of this so-called “tamed chance” became more controlled by this new kind of law that came into play. “The greater the level of indeterminism in our conception of the world and of people, the higher the expected level of control” (1990: vii). This highlights the contrast with the pious attitude of the creation out of chance that can be perceived in the example of Mallarmé’s *Un coup de dés jamais n'abolira le hasard* (1914), a reflection on chance and cutting across chance, it exhibits the constitution of a divination exercise, an evoking or conjuring appeal of the oracular “constellation” of meaning that is, although by chance, nevertheless meaningful: each throw of the dice emits a thought. Deleuze unambiguously asked in this direction: “What does it mean, therefore, to affirm the whole of chance, every time, in a single time?” (2004: 198) His response is direct and lucid:

> This affirmation takes place to the degree that the disparates which emanate from a throw begin to resonate, thereby forming a problem. The whole of chance is then indeed in each throw, even though this be partial, and it is there in a single time even though the combination produced is the object of a progressive determination. (ibid.)

This means: the individual and finite throws are not cancelled by the endless whole of chance, but ‘resonate’ together in it by way of its serial explanation. An individual, finite throw in Deleuze must be read as the *index* of a class of potentially endless ‘bifurcations’ through the ‘branches’ formed by all possible series of upcoming throws. Throws, for both an oracle or a computer-generated random result, have nothing to signify, they stay on the surface. They are far from the deeper layers of meanings and intelligible reasons. We can see how this pertains to the tradition of divination practices, where no one claims to comprehend the deep meaning of reality –set aside for God’s view and perpetually out of reach of human knowledge. They navigate on the surface, attempting to receive evidence of the pervasive order of things out of forms and their recursivity.

Divination, in a certain sense, is capable of employing, or rather invoking, a sort of irreversible puzzle within actuality: the fact that actuality is never completely itself, because it is always riddled with a contingency that unlocks the actual onto the very magnitude that divination seizes. This is why (as manifestly expressed throughout this brief overview) divination practices entail the subordination of some critical elements in the present (shells, coins, dripping blood etc.) to unequivocally random techniques, as if chance were not the final frontier of events but some alien *liason* between past, present and future actualities.

Chance from this perspective is enacted not abstractly but concretely, by means of, for example, an actual throw of a dice. And this event is by its very nature relational: the reason for what occurs (in a divining chance) is more than hard necessity, more than simple material or efficient cause, particularly as far as chance is *enacted*; *absorbed*. Divination does not consider the abstract future, but tracks the constituents of the present (e.g.: dice throw, patterns exhibited by nature) in order to follow up a random process into its concrete, contingent potencies. In a certain way, divination takes advantage of the fact that contingency itself is not the diversion of the actual from a random set of possibilities but the result of a dynamic strain within the actual itself. According to this, contingency is related to the incessant rather than with the singular instantiation –with a continuity, however transient and obscure, rather than a categorical interruption of the real. Such is the enlightenment of divination: in order for there to be contingency, the random specific relations of any given world need to be understood as unconditionally features of that world.

4.3: Prescient Machines?

It is hard to overstate the anticipated potential and current enthusiasm associated with the algorithmic regimes of knowledge production. It is interesting to note how the very same underlying logic of divination is shared by the "web intelligence"[151], since both refuse to advance in a linear way from cause to effect, from question to answer, from past to future. Data mining (in particular web mining), information retrieval, pattern recognition, predictive analytics, are looking for patterns and correlations that would define the outcome of the activity or enterprise for which they work. Predictive algorithms aim to retrieve and read the past, present, or future commutatively, since any of them (if properly deciphered) reveals the same order and the very same logic. Predictive algorithms disclose an order that their very processes have no interest in comprehending nor the capacity to do so. The sequence is set in a meaningful "synchronicity" (events that seem connected but are not causally related), where the past can provide insights about the future, due to the fact that they have to conform to the same formal conditions and the very same logic. As opposed to causality, a general synchronicity (Jung, 1952) intervenes, providing a completely different significance to

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[151] The different fields that encompass data mining (in particular web mining), information retrieval, pattern recognition, predictive analytics, the semantic web etc.

prophesying the future: it is not an issue of forecasting a future that does not yet exist, but of disclosing the necessity registered in the order of things, of appointing the advantageous or disadvantageous conditions and the times that would determine the achievement of a goal. Ultimately, in both divination and predictive analytics, information is not ascribed to communication. Contrary to the etymological root of the word oracle, that comes from the Latin verb *ōrāre*, "to speak", we do not 'speak' with "web intelligence technologies" as the priestess uttering the prediction does not speak with the oracle. These do not manifest their views and do not comprise their 'conscience', but simply *disclose*, *unveil* information hidden in the order of things, which is deciphered for the purpose of *clearing* its opacity, not to comprehend what the one ("web intelligence technologies" or oracle) who articulated it had in mind.

In the age of unlimited data and vast computing power, the potential provided by predictive analytics is potentially free of subjective bias (although, if machines are 'fed' with biased data, they will generate biased results), and correlations computed at scale are less vulnerable to uncertainties resulting from generalisations and sampling. As well as offering comprehensive perspectives on the general situation, predictive analytics provide a bespoke 'truth' targetted to individual users as an outcome of 'their' data, independent of the context. Data asymmetries (disparity in access to data) entrenched within the technological, institutional, and business milieu, generate subsequent imbalances of power and value[152]. Modernity, understood as a large-scale control and prediction of the environment, is built on certain epistemological uncertainties or asymmetries. In the present asymmetric context, corporations cannot break new ground with linear models and static tools. Conversely they try to increase the exposure to positive asymmetries (understood as opportunities) and minimize the exposure to negative asymmetries (understood as risk). They try to achieve a "antifragile" gain from disorder, volatility, and *noise*. As made explicit by Taleb: "to benefit from the positive side of uncertainty, without a corresponding serious harm from the negative side" (2012: 216).

Prediction or divination helps us accelerate decision making, they 'help' us to avoid making judgements. Particularly when we do not always have sufficient information but still need to

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[152] See: Zuboff, S (2018) *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power*. London: Profile Books.

make a choice. As highly technologically-mediated agents, our past and the future are just present as information retrieval and expectations that influence perception[153], past and future are negotiated arrangements of a present function, and can, in truth, differ from what in fact occurred in the past or what will take place in the future. In fact, we might even argue that since the present vanishes in *no time*, we are capable of *building* time as we consider, on the basis of an alternative present (which we encounter without further ado), we can revise and modify our recollections of the past and forecasts of the future.

4.4: Calculation of "futurability"

The riddle of time relies on the way in which past and future are never given, but become instantiated as frontiers of "inactuality" (Luhmann, 2000: 160) for an always perennial present. We deal with time in such a way, because it may be assumed, that past and future, as inactual, award us more autonomy. The inactual provides benefits since it grants us an increased liberty in arranging our decisions and limitations. For the purpose of taking this case into consideration, we nonetheless, require "a completely different concept of time" (Luhmann, 1996: 9), one that is capable of exploiting the systems' potential of orienting themselves to further and further articulated spaces of inactuality as an asset (in the capitalist sense of course. Capitalists buy and sell "futures"), which enables the re-arrangement of its limits and guarantees a form of coherence to the flux of time, since we deal with the same challenge of a time that is edified in a moment in which we do not recognise as present, given the continuous and immediate cancellation of it in the transit to another present.

Unknowability about the future is being turned into computable assets as well as governable risk. Uncertainty is more than an issue of a lack of big data, of more tracking, more information and more knowledge. Ramon Llull, with his *Ars magna* (ultimate general art) from 1308[154] conjured a "mechanical" system of thought to resolve, scientific, theological, moral and legal debates, to: "banish all erroneous opinions" and to arrive at "true intellectual certitude removed from any doubt" (Llull, 2003). The basis underpinning Llull's *Ars Magna*

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[153] See: McClelland, J.L. and Rumelhart, D.E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review*. 88, 5. pp. 375–407.

[154] Llull dedicated himself to designing and building a logical machine where theories, subjects, and theological predicates were organized in geometric figures of those considered "perfect" and by operating it a few, the propositions and theses move along guides and stop in front of the positive (certainty) or negative (error) position as appropriate. According to Llull, the machine can prove for itself the truth or the lie of a postulate.

was Majorcan mysticism and medieval Arabic divination, the *zairja*, an algorithmic process of "letter magic" for calculating truth on the basis of a finite number of elements. Its practitioners would give advice or make predictions on the basis of interpretations of strings of letters resulting from a calculation. In 1666, Leibniz wrote *De Arte Combinatoria* (On the Combinatorial Art), an extended version of his doctoral dissertation in philosophy, highly influenced by the works of Ramon Llull[155]. His *art* would enable its practitioners to prodigiously produce new concepts, novel developments and at the same time that would be able to dissolve and scale down complex questions to simple elements and conceptual toy models.

In recent years, Quentin Meillassoux has been countering such imagined total computability by arguing about "hyper-chaos" (2014: 26-27) or true uncertainty, where we cannot ascribe probabilities to all the possible states of the universe because there is no such settled or closed set of all possible states in the first place. "[I]s the idea of a time so completely liberated from metaphysical necessity that nothing constrains it: neither becoming, nor the substratum" (ibid.). There is no totality of cases, even if our computational imagination obtains, where everything could be rendered computable with the assistance of a *characteristica universalis*[156]accomplishing the numerological dreams of the Pythagoreans.

"As the future is not prescribed, and the succession of now and tomorrow is not monolithic or determined, our task consists in distinguishing the layers of futurability that lie in the texture of the present reality" (Bifo, 2017: 17). As we see, the *production* of the future invariably relates to the issue of risk, the awareness of the fact that future opportunities rely on the decisions of today –which are continuously uncertain, since the future that we build stays veiled. Prediction constantly relies on relatively necessary futurabilities, e.g.:

> If you don't pay the rent, you will be evicted' [...]. There is no logical necessity in the implication, but social relations are based on the enforcement of conventional rules.

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[155] For more on Llull's influence on Leibniz see: e.g., Antognazza, M.R. (2009) *Leibniz: An Intellectual Biography*, Cambridge: Cambridge University Press, pp. 40, 62; Loemker, L.E. (1973) Leibniz and the Herborn Encyclopedists. In: Leclerc, I. (ed.) The Philosophy of Leibniz and the Modern World, Nashville: Vanderbilt University Press; Eco, U. (1995). *The Search for the Perfect Language*. Oxford: Blackwell; Welch, J.R. (1990) Llull and Leibniz: The Logic of Discovery. *Catalan Review*. 4. pp. 75-83; Maróstica, A. (1992) Ars Combinatoria and Time: Llull, Leibniz and Peirce. *Studia Lulliana*, 32, 2. pp. 105-134.

[156] Leibniz imagines a "universal language" of human thought made up of pictographic symbols/elements (like hieroglyphs and Chinese) being able to express mathematical, scientific and metaphysical concepts.
See: Mates, B. (1986) *The Philosophy of Leibniz*. Oxford: Oxford University Press.

> This enforcement may happen by force of violence, of agreement, or by force of automation.
> In the computer of the real estate company, there are logical chains implying that the tenant who does not pay the rent will be expelled from the house. This implication, however, is neither logical nor natural, but is enforced by the automation of will, and by the automated transcription of a social *rapport de force*. Financial capitalism is bound up in techno-linguistic implications that pretend to be natural and logical. They are not. They are rather artificial reductions of the range of possibility to the narrow string of probability. (Berardi, 2017: 17–18)

When we perform predictions, we do calculate our futurabilities. We consider risk when we need to choose what action should be taken in the present, being aware that in the future we must either take advantage or deprecate our past actions (if we take the standpoint of a future "present in the present", we can experience a loss or damage that can be imputed to the current choice). E.g.: "if we had not eased the lockdown in the recent weeks of the pandemic, our healthcare system would still be able to cope with a second wave". The same applies to positive outcomes: "if we had not put the country on lockdown, our healthcare system would have collapsed by now". The riddle that we have to address in the present is that the 'win' and 'lose' conditions express the same indifference toward human values, and we are not able to see how events will be arranged today –even if we know beforehand that we will correlate the result to the decision-making. We are not able even to recognise what we should consider, or to which standards we should conform (which invalidates the common methods of time-binding)[157], due to the fact that the very risk assessment is altered with risk and time itself. If events create positive or negative outcomes, we will be more or less prone to assume risks. In other words: a positive feedback that can drive an unrestrained amplification loop of risks, as the dynamics of financial systems show.

Hence, it is not possible to elude risk. We risk if we decide to take the *chance* and there is a negative turn of events, but we also risk if we refuse to take the opportunity, and then we lose the advantage. The world has nothing to inform us on this regard, since the question is about a future that does not yet exist and, therefore, it is not able to contribute with any guidance about the positive or negative paths to take. There are no normative standards of rationality

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[157] As a human group we participate in time-binding, and it is partly on this basis, where cultures are able to evolve. "A culture is an experiment in the storage of information for reuse" (Strate, 2017: 431).

that can ensure that we are not going to lament this in the future, because there is no reason to believe that in this future (that does not exist) we will think exactly in the same manner.

4.5: A Whole New Riddle?

> The problem of cybernetics is no longer forecasting the future but reproducing the present (Tiqqun, 2020: 56)

In Nelson Goodman's, *Fact, Fiction and Forecast* (1983), the notion of "projectible predication" is raised in order to draw a distinction between hypotheses premised on regularities in experience and those which are not. Goodman provided various "riddles"[158] created to emphasize some of the logical problems concerning inductive inference[159] and its scientific application. There is an analogous assessment of counterfactuals participating in correlations supported by experience and those which are not – If X, then Y, and not-x, as in: "if the liquid in this bottle was composed of cyanide, it would be poisonous but it is actually still water". He states that if we "seek a theory at all we cannot excuse gross anomalies". Grounding scientific theories on inductive inference may bring us a "widespread and destructive malady" (1983: 80). As argued by Hume, knowledge about the past and/or present of an object or phenomenon, cannot guarantee itself in the future because observation (on which such knowledge is grounded) is by definition something that can only occur in the present. We can record observations (the *record* of *past projections* of predicates in competing hypotheses), and thus future observers can inherit them from us, but they are of course, always from the past, and speak only of what had been the case up to that moment in time. If we cannot rely on observation in regard to the future, we must rely on speculation, which is more successful when we use logically valid methods of reasoning, which we call

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[158] "Let "*x* is grue" be defined as "*x* is examined before time *t* and found to be green or *x* is not so examined and is blue". There appear to be no formal arguments to demonstrate that "All emeralds are green" is lawlike, but "All emeralds are grue" is not. Why then should we accept the former rather than the latter since (*t* being some future time) both are equally compatible with the evidence? This is the new riddle of induction." (Elgin 1997: 42-3)

[159] Goodman "protest[s] against the prevalent notion that the problem of justifying induction… can fairly be called Hume's problem". (1983: 61). The problem is not to *justify* it but rather to locate the source of our predictive 'powers' in science. Hume's response to this would be: "nature". And we could argue that *this* becomes Goodman's problem in Hume's perspective: what is the source of the order that we make? Hume maintains that reason is neither entitled to infer the resemblance of future to past events, nor "that the course of nature continues always uniformly the same." (1978: I.3.vi).

induction. But the problem of induction is for Hume: how to identify which present experience we should be guided by in our moral reasonings, concerning matters of fact of existence (nature) and experience (human nature) and in our speculative reasonings, concerning what can and cannot be inferred from relations of ideas. What for Hume remains an inquiry into nature's "hidden springs" becomes, for Goodman, a question of including prediction as one among the many facts about the world itself; in other words, prediction is a picturing that, in part, makes what it pictures. Prediction is (partly) constitutive of that which it predicts. If nature's uniformity is indeed undermined, not least due to the fact that our "object-domains" (ontologies), our systems and orderings, are subject to "extension and modification" (1983: 67) and even "invention" (1984: 37-38), what prevents us from stating that this is only natural?

We can in fact presuppose nature's uniformity, which does not sound too unreasonable when we make claims about photosynthesis, magnetic fields, or perceptible objects such as rivers and fruits. We are able to project various attributes and properties to these entities with a fair degree of certainty long into the future, taking into account our past experience of these objects and phenomena. But this principle proves itself quite fallible when applied to human behaviour. Humans are extremely hard to model[160], and this is a crucial fact because the registered behaviour of humans is the fuel for machine learning. This is known as "behavioural big data" (Shmueli, 2016), and without it, the AI-powered recommendations we receive daily while browsing the internet would stop functioning.

If we would like to infer a human's priorities, necessities, aspirations, and concerns, we would need to take into consideration their social, individual and moral identity. We would need to produce an introspective recount of the person's development, and take into account many other areas of their dense inner world. At the moment, machine learning is not capable of generating such a thing, and philosophers of mind have been claiming since the 1980s (even though it has been evident for philosophers for much longer than that[161]) that this might

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[160] Yanis Varoufakis describes this as "radical indeterminacy". See: Varoufakis. Y. (2013) *Economic Indeterminacy: A personal encounter with the economists' peculiar nemesis*. London: Routledge.

[161] It could have begun with Descartes bifurcation of the machinic body and immaterial cogito. It is then subject to repeated reformulation, and denial. It has certainly been further highlighted in the last 100 years as neuroscience has come on in leaps and bounds, such that various aspects of the neurological basis of human functioning and behaviour have been uncovered –but without any apparent advance whatever in resolving this "explanatory gap". Arguably it cannot be solved as a matter of principle as long as dominant scientific ontologies insist that the material world is devoid of 'mental' content of any kind.

not be even possible, because of an "explanatory gap" (Levine, 1983) between subjective experience (my *feeling* of pain) and objective, physical facts (C-fibers firing). This "explanatory gap" might very well be understood in terms of noise that inductive analytics cannot completely overcome. Humans change and evolve socially and morally in non-linear, non-transitive ways. These sort of steep structural transformations to our social and moral identities are not properly addressed in inductive inferences. Machine learning personalization encounters even more difficulties trying to understand how our judgements change in a sheer and unpredictable manner, such as dramatic or major events that can take place in our life. Even more complex for the science of prediction is that socio-political and moral change seems immune to induction. In retrospect, changes like universal suffrage or the fall of the Berlin wall appear inexorable, but from the perspective of those who lived that moment in time, *past instances will not resemble future ones*. There are limits to prediction based on induction, but it is clear that behavioural prediction and modification is taken place in the socio-political sphere – such is the case of Facebook–Cambridge Analytica data scandal[162]. It could be argued that what begins with prediction and modification of consumption patterns, moves on to voting behaviour, and eventuates, in the minds of transhumanists, in the total "data grid" as Rosi Braidotti calls it (Shafaieh, 2019). What it is argued here is that there is a piece of 'grit' in the machine, so to speak. *Noise* that makes such a "total data grid" ultimately *impossible*. That does not mean that the machine cannot go a long way towards such control, or that it does not have to be actively *resisted*.

4.6: From Markov to Autocomplete

On the Internet, where the number of options is paralyzing, it is necessary to filter, to establish priorities and competently provide relevant information in the interest of mitigating the issue of information overload –which has constituted a difficult challenge to many Internet users.

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[162] See: The Cambridge Analytica Files [online]. Available from: https://www.theguardian.com/news/series/cambridge-analytica-files [Accessed 16 June 2020], ongoing investigative reporting from The Observer/The Guardian, beginning 17 March 2018, part of News: Cambridge Analytica beginning a year earlier.

Predictive analytics are a good example of the ongoing transformation in the hyperstitional[163] affair between knowledge and data, operating as a 'special guest' in the enactment of information processing's epistemic quest.

Google established "Autocomplete" as a predetermined configuration in their web search engine in 2008 (Liu, 2008). Since then, it has been frequently mentioned in the mainstream media not as a tool to accelerate facilitate and search enquiries, but as a "service that taps into humanity's collective psyche" (Garber, 2013) and reveals "some of the hidden intentionality behind […] the peculiar statistics of a world id" (Lewis-Kraus, 2014). The view under which word prediction software serves as proof of the behaviour and aggregate values of a society is so fascinating, that even in a research paper that critically examines the "Google Flu Trends" failure[164], as well as the "traps" of predictive capacities of search query data, the authors naively depict it "as data on the desires, thoughts, and the connections of humanity" (David Lazer et al, 2014). What is truly fascinating is how autocomplete text suggestions use machine learning to continuously improve the model. As a result, autocomplete algorithms are quite good at predicting what I want to type more or less on the basis of what I have typed before and what others have typed. But the suggestions do not need to predict what I want to type, they change my behaviour to make the prediction fit. Instead of typing a sentence, I hit one button and the sentence autocomplete algorithms 'think' I wanted to type appears, maybe it is not quite what I would have written had I typed it myself, but it does not matter, the feedback is reinforcing, I have now typed what the autocomplete algorithm suggested.

In 1906, almost a century before Google Autocomplete, Russian mathematician Andrei Andreevich Markov founded a novel branch within probability theory. Increasing its field of activity and incorporating the prediction of dependent random events; events that only depend on what happened last.[165] Additionally, he claimed that certain predictions about stochastic processes can be easier to understand in terms of a *future independent of the past* – given the present state of the process. We apply this in order to simplify predictions about the

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[163] Hyperstition is an "[e]lement of effective culture that makes itself real, through fictional quantities functioning as time-travelling potentials". Ccru (Eds.) (1999) *Abstract Culture: Digital Hyperstition*, London: Ccru p.74.

[164] Google Flu Trends failed spectacularly missing at the peak of the 2013 flu season by 140 percent (Lazer et al, 2014).

[165] Markov first discussed the general concept of chain dependence in *Rasprostranenie zakona bol'shih chisel na velichiny, zavisyaschie drug ot druga*, published in 1906. See: Sheynin, O.B. (1989) A.A. Markov's Work on Probability, *Archive for History of Exact Sciences*, 39, 4. pp. 337-377.

future state of a stochastic process. Markov's "general theory of chain dependence" unleashed a new range of real-world processes from our daily lives to become subject to probabilistic calculation. "Markov Analysis" is very advantageous in the process of decision-making since it provides a probabilistic description of various outcomes. Among its many contributions, it is most remarkable for its applications in information theory, and therefore, computer science and communications. Nowadays, Markov processes are ubiquitous in information technologies that support many different sorts of knowledge production: assisting in the identification of genes in DNA, the mapping of animal life populations or the design of search-engine algorithms. It is interesting to note that in 1913, when Markov empirically confirmed his theory, it was by means of the prediction of text. Using a copy of Alexander Pushkin's *Eugene Onegin*, he showed that in a text like Pushkin's novel, the chance of a certain letter appearing at some point is dependent (to a certain degree) on the letter that came before it.[166] A new 'island' of probabilistic knowledge was 'conquered' through the practice of vowels and consonants 'divination'. This genealogy of predictive analytics, helps us to understand the ways in which an emergent "epistemic machinery"[167] is reshaped and deeply ingrained in electronic mass media and digital communications. It helps us to elucidate what kind of processes made language compliant to the requests of data processing; how data processing (as a way of access and production of knowledge) became not only plausible, but desirable and consequently naturalised; and how, this epistemic structure contributed to the expansion of predictive processes across many different fields of activity: encoded in the technical protocols of *everything* from algorithmic financial trading to real estate recommendation engines (Yuan et al., 2013).

4.6.1: Pitfalls of Big Data Correlations

We know patterns are relative to information processing dynamics; *just as noise is* (Wilkins, 2021). That being said, this does not render them merely 'subjective'. There is an observer-dependent reality for the identification of patterns in connexion to the particular aspects of the functional operation of the system and the information processing power, establishing a 'perspective' that is regulated by diverse conditions: the spatio-temporal distribution of the

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[166] Markov, A.A. (2006) An Example of Statistical Investigation of the Text Eugene Onegin Concerning the Connection of Samples in Chains, trans. Gloria Custance et al., *Science in Context* 19, 4. pp. 591–600.

[167] As understood by Knorr Cetina as the "different architectures of empirical approaches, specific constructions of the referent, particular ontologies of instruments, and different social machines" (1999: 3).

pattern, the sensory input constraints and the human cognitive capacities for calculating the result, the evolutionarily trends (pattern of directional change), the computational resource allocation decisions etc. Unlike patterns, the result of an examination of a random system is unpredictable. Every resulting measurement 'comes as new'. That subsequent little 'revelation' provides us information about the system. We are required to continue examining the system in order to observe the changes in its evolution. We perceive the construction of models as equivalent to deciphering nature's 'hidden knowledge'. How are we able to make sense of the arrangement of a system or its relationship with random processes, given only the possible, mediated measurements that instruments offer?

The most naïve illustration of the moment we are living in this regard, could be the paradigmatic presumptuously scientific (but flawed) data mining on Big Data, as huge quarries of information. The very well-known mantra of "data is the new oil" (*The Economist*, 2017), and online 'platforms' are the best way of getting such data (Srnicek, 2016): "[d]ata to be the raw material that must be extracted, and the activities of users to be the natural source of this raw material. Just like oil, data is a material to be extracted, refined, and used in a variety of ways. The more data one has, the more uses one can make of them." (2016: 28). Over-simplistic (salesman's) metaphors like this are extremely dangerous in a present in which platforms like Facebook and Google are moving to regions like India and Africa (Thatcher et al., 2016) in a pursuit of colonising new lands so they are brought into the global capitalist network as locations of extraction (Moore, 2015). They do so in the name of the 'emancipatory potential' of technology providing subsidised services to marginalized ethnic groups with poorer (or no) internet access (Weidmann et al., 2016) , yet the corporations benefit immensely by opening new markets, facilitating the entrapment of customer labour into their platforms, and exploiting sources of data. These new locations with new people supply new possibilities for data accumulation. The very same imperialist and colonialist strategies are being reenacted now, but reviewed for the digital age. It is the "convenience in return for your soul" deal. In Aristotelian terms, that is literally the deal. It really is your *psuche* they are extracting.

Data mining is a deceptive notion; a more appropriate term would be "re-composition of data-value". Data is not 'out there' waiting to be extracted as if it already exists in nature like crude oil and raw ore (Gitelman, 2013). Unlike oil, Data is not a fungible commodity, at the same time that it is non-scarce. As Rob Lucas puts it, data can be understood as a "[representation], and it takes magical thinking to equate representation with possession. If someone spies on me and notes what I do, my behaviour is still no less mine. It has, of course, left its imprint in something I do not possess, but then I didn't possess that in the first place" (2020: 139). Data is a *recorded* abstraction of the world produced and valorised by workers, extremely mediated by technology. We need to remember, as Marx stated, that:

> [W]henever, by an exchange, we equate as values our different products, by that very act, we also equate, as human labour, the different kinds of labour expended upon them. We are not aware of this, nevertheless we do it. Value, therefore, does not stalk about with a label describing what it is. It is value, rather, that converts every product into a social hieroglyphic. (Marx, 2000b: 474)

It is in the instantiation of processes of accumulation by dispossession and colonization of the life-world (Thatcher et al., 2016) (by means of the sophisticated commodification and extraction of personal information) in which data is presented as a natural resource. This is how platforms are able to sustain the claim that they have simply hoovered up some stuff that nobody else wanted, rather than appropriated something that was not theirs to appropriate – our thoughts, desires, preferences, impulses, feelings, fears, aversions, hates… Resources that not only would contain an intrinsic value but also are expected to predict all sorts of dynamics and to guide our decisions, without the need of our knowledge, theories and the elaboration of our hypothesis (Anderson, 2008).

It is important to keep in mind that we consider the statistical analysis of extremely large data sets an extraordinary and unprecedented opportunity for checking theories, generating novel hypothesis and expanding the scope of speculative ideas and thought. Unfortunately, the actual tendency we are observing nowadays, is the assumption under which thought can be streamlined compressing it to the point that it could be replaced by algorithms. Decision making and thinking are no longer soundly processed, since we have access to machines that identify regularities that science cannot tackle and their algorithms are powerful enough to predict and take action regardless. As the General Michael Hayden, (former director of the NSA and the CIA) stated: "We kill people based on Data Mining on metadata" (Johns Hopkins University, 2014). What it is even bleaker, is that the "asymmetrical extraction of value [from data] is shown to presume both quantification and surveillance of the lifeworld, of lived experience, *as a natural, desired outcome of modern lif*e" (Thatcher et al., 2016: 2, emphasis added). However, it is encouraging to see how some of these incongruities are being debunked –with the help of maths. The work of Calude and Longo (2016) in their paper ‘Deluge of Spurious Correlations in Big Data’ is highly remarkable in this regard. They explain how “very large databases have to contain arbitrary correlations. These correlations appear only due to the size, not the nature, of data. They can be found in ‘‘randomly’’ generated, large enough databases, which […] implies that most correlations are spurious.” (2016: 595). We can compute a number of elements for any given correlation between numbers, we could say *n*, such that all sets of numbers comprising at least *n* elements comply with the pre-given correlation (Longo, 2020). Consequently, it is the same case for a database, result of a random process, by a ‘‘random’’ way: by throwing a dice or measuring a quantum observable (Calude and Longo, 2016: 606) The correlation will also arise there and will then be “spurious”, because it appears by chance.

Put differently, the appearance of correlations may rest on the size of the dataset and not as a result of a prophetic nature of the predictive algorithm. In large sets of numbers randomness is unavoidably. Because of this: any sort of prediction that is not grounded on a conceptual production that confers meaning and that makes it possible to determine the relevance of the assertion; is risky – hazardous by definition. Conceptual production is required in order to attain knowledge and generate theories, and whenever possible, make predictions.

The methods and principles of science show us the threshold of the intended theory (where randomness operates); this contributes to the production of an improved knowledge, determining constraints at the same time that strengthens the attitude that makes it possible to do scientific work. “Those who pretend to understand everything and to be able to make everything from a single object or concept, such as the DNA in biology or information, algorithms in all sciences ... they are certainly wrong” (Longo, 2020: 76).

This, remarkably contrasts the “dataist” (Brooks, 2013) ‘faith’ in a deluge of data that would make the scientific method obsolete (Anderson, 2008). The form of the world arises in noise (the “pre-individual” as characterised in chapter 3), so it cannot be digitally mapped in totality outside of that morphogenetic process. There is no potential *noiseless* “control grid” or “final solution” as imagined by Anderson and others. The ‘noiseless’ ontological fantasy behind predictive analytics sins of hubris. Aiming for a total prediction/control fantasy that is nothing but a ‘fascistic’ one. Transhumanism/dataism is arguably another grasp at the ‘final solution'. As ever, though, it is not the impossible final solution itself that is the problem, but the socio-political horror that the fantasy motivates. The technoscientific assemblage facilitates this horror. While pattern recognition contributes positively to our survival instinct, it is now being exploited during a time of governmental crisis, global pandemics and social paranoia. The apparent affinity between the platforms and the massive amplification of conspiracy theory[168] (a phenomenon often associated, in the past[169], with the desire for purification and control) corroborates the exploitation of people's own anxieties. Given how conspiracy theories tend to emerge[170] during times of crises as a means of trying to take back control over an irrevocably *chaotic* world.

4.6.2: Normative Production of Prediction: *is this it*?

In this context of overwhelming deluge of data, Recommender Systems (RS) constitute information filtering mechanisms which filter vast amounts of dynamically generated information. They can be tracked down to the expansive work in the fields of cognitive science, approximation theory, information retrieval, forecasting theories, and also have connections with management science and "consumer choice modelling" in marketing. "They were initially based on demographic, content-based and collaborative filtering. Currently, these systems are incorporating social information. [They] use implicit, local and personal information" (Bobadilla et al., 2013: 109). Their applications are ubiquitous –from content recommenders on social media platforms to online dating apps. The algorithms of RS constitute automated systems that provide recommendations relying on predictive algorithmic models. One of the most prominent algorithmic techniques employed in RS, is collaborative filtering. As Chopra and Balakrishnan indicate: "They work by extrapolating unobserved user-item preferences from preference information collected from the target user, and the preferences of all the other users. Finally, recommendations are made, and the user can be

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[168] See: Allington, D., Duffy, B., Wessely, S., Dhavan, N. and Rubin, J. (2020). Health-protective behaviour, social media usage and conspiracy belief during the COVID-19 public health emergency. *Psychological Medicine.* pp. 1–7; Bruns. A., Harrington, S. and Hurcombe, E. (2020) 'Corona? 5G? or both?': the dynamics of COVID-19/5G conspiracy theories on Facebook. *Media International Australia.* and Frenkel, S., Decker, B. and Alba, D. (2020) How the 'Plandemic' Movie and Its Falsehoods Spread Widely Online. *New York Times*. [online] Available from: https://www.nytimes.com/2020/05/20/technology/plandemic-movie-youtube-facebook-coronavirus.html. [Accessed 25 September 2020]

[169] See: Waters, A. (1997) Conspiracy Theories as Ethnosociologies: Explanation and Intention in African American Political Culture. *Journal of Black Studies*, 28, 1. pp. 112-125.

[170] See: Knapp, R.H. (1944) A Psychology of Rumor. *Public Opinion Quarterly*, 8 ,1. pp – 22–37.

shown the items estimated to be the most preferred by her." (2012: 143) Along those lines, Schroff points out: "there is no distinction between 'objects' and 'features' […] Books are objects with the people who buy them as features. Similarly for films or ratings. The features that emerge out of collaborative filtering are hidden, or 'latent', such as the roles people play." (2015: 118).

The employment of data mining algorithms is, ultimately, about controlling and predicting behaviour and identity. In view of this, former Google-CEO Eric Schmidt and his co-author Jared Cohen clearly expressed that they think "[i]dentity will be the most valuable commodity for citizens in the future, and it will exist primarily online […] [w]e are what we tweet" (Schmidt and Cohen, 2013). RS generates a comparative cartographic model between our preferences and those of others, offering new or ignored fragments of culture for us to encounter. Algorithms oversee our interactions on social networks, highlighting the content of one user while omitting another's. The oscillation between emulation and deviation conducted by these RS needs to be understood, as a "techno-social activity", comprising an interactive and iterative operation between the algorithms' and users' actions.

The differentiation between norm-instituting and norm-following is important here to further comprehend the distinction between two operational determinations. The majority of technical entities present a relevant ''margin of indetermination'' that renders them compliant to ''external information'' to a certain extent, as well as receptive to ''internal transformations'' (see Simondon, 1958: 134-152). We see this in the gradual and mutual wear and tear between a nut and its threaded bolt, in a speed governor device that controls the speed of an engine under fluctuating load and pressure conditions, or in the response of an RS to the latest interactions between users and algorithms. The difference between norm-instituting and norm-following can therefore be thought of in terms of different forms of determination: a determination could be understood as ''convergent'' or ''divergent'' on the basis of whether it restrains or increases the "predictional variability" of an RS. From this perspective, the particular predictions of an RS are subjected to periodic transformation (i.e. the parameters of the model are reviewed) according to the pertinent new input of data –i.e. specific sets of information. Generally, an engineer's role is to restrain RS's variations and orientate them towards corporation objectives. Although the determinations of Machine-learning algorithms can be perceived as leaning toward quite particular preestablish norms, in fact, the learning activity as such, as Adrian Mackenzie (2018: 82) has claimed, is closer to stochastic “function-finding” (Mackenzie, 2015: 435) than to deterministic “function-execution”. A new produced model would respond to one within many potential arrangements. From here it is now possible to think about the relevance and meaning behind machine learning algorithms ‘behaving’ in unpredicted and fortuitous ways, allowing the possibility that they become spaces of “normative innovation”.

Developers working on RS, have been recently recognizing as well the problem of induction and the implied presumptions about the uniformity of nature. Accordingly, RS often inject randomness into their predictions. “Random forest”[171] (Zhang and Min, 2016), “Markov decision processes” (Shani, Heckerman, and Brafman, 2005) and “random walk algorithms”[172] (Semage, 2017) have been used in RS in many different models and following various approaches. Basically, by means of inserting an ingredient of randomness into predictions for the purpose of preventing a bland recycling of recommendations. What is fascinating is the way in which developers try to mirror human’s non-linear and non-transitive processes, in order to systematize, implement and measure “serendipity” in their predictions (Ge, Delgado, and Jannach, 2010). The difficulties, in the case of machine learning, are attached to the irregular distributions of human and machine behaviours (Collins, 1990) and to the extraordinary competence algorithmic systems have of establishing norms[173]. We need to acknowledge that Big Data marketing (which aims to increase consumer surveillance and control (Zuboff, 2015)), is frequently portrayed by the platforms as characterised by a contemporary spirit of collaborative ‘in-this-together-ness’ and structures of collective help between corporations and users. However, these *are* algorithms that determine what news we read, which food we buy, which music we listen to. Ethical challenges of RS were signalled by Milano, Taddeo and Floridi (2020). Predictability is at the semiotic level of human communication, the equivalent to the exploitation of ‘dead’ parameters or data traces, as Kenneth Burke states: “[…] it is in this way that a man defies total prediction until he is finished. Indeed, prediction is in effect the application to living

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[171] Random forests start with the idea of decision tree. ‘Forest’ because there are several trees, ‘random’ because each tree is only trained on a random subset of samples drawn from the training set (with repetition) and possibly a random subset of features. The ‘random’ part is needed because otherwise, the trees would be so similar that there would be no advantage in having a ‘forest’.

[172] A stochastic process in which the initial state is known and the next state is governed by a transition probability that indicates the chances of e.g. jumping from one node to another in a graph.

[173] Machine learning algorithms calculate vector norms in order to know the difference between the predicted and the actual results.

man of parameters derived from the realm of death; that is, the possibilities of the future are reduced to terms derived from the past." (2003: 236).

This strain can be partially reformulated as the question of situating these predictions in relation to the techno-social activities within which they take place, and that they actively participate in their formation. The notion of a "predictional normativity" accentuates the relevance of chance operations and the therefore related region of indetermination that enables predictions which are informative for the user.

> "[N]oise" is a behavior that would escape control while remaining refractory to the system, that is, one that cannot be processed by a binary machine, reduced to a 0 or a 1. Such noises are the lines of escape, the divagations of desires that are not yet entered into the circuit of valorization—the non-inscribed. (Tiqqun, 2020: 125)

If there is no margin for error, then all predictions that do not perform or conform with the determined and programmed norm will be ignored or suppressed as pointless or unfit. On the other hand, those predictions that do not result as anticipated can be engaged in inducting a novel norm-following dynamic. Thus, machine learning compels us to re-examine those predictions that are redundant and those that create new norms.

4.7: Conclusion: Neotechnical Sacrifice

In the contemporary world chance is allegedly rendered useful not by means of divinatory rites but from the viewpoint of complex adaptive systems science, with examples that range from information processing to animal swarms or economic systems, these integrate the random or unpredictable as one of their functional or evolutionary parameters (Atlan, 2010). The significance of chance is presumed to be manifest only in terms of abstraction supplied by big groups of data to the disingenuous view of the researcher or the disinterested operations of an algorithm. This solemn standpoint is in intense friction, nevertheless, with the attraction of the contemporary subject towards the extraordinary specificity of chance (Hacking, 2006; Lear, 2003).

It is therefore highly relevant to understand algorithmic prediction as a kind of divination, since divinatory insight is broadly that which we count on in order to orient ourselves adequately to a present decided by powers otherwise obscured in the past and in the future that could not have been foreseen. With the intentional injection of chance in algorithmic platforms, emerges a paradoxical rereading of the past and the expectation of the future as contingent –as not what it appears to be. There is, accordingly, a divinatory approach towards algorithms in technocapitalism. Divination, by searching for occult or unidentified patterns/correlations/repetitions (not reasons as such), is a sort of emancipation of the present from its seemingly impounded character or as an inevitable closure. Algorithmic divination is able to persuade us to keep trying to rearrange the future in the inception of a past that never was –a past that *could* have been (and 'must' have been) envisioned by an entirely functional algorithmic decision-making process. Our critique of algorithmic/computational "microfundamentalism" argues that it envisages a single oracle, a single communication and a single chance: for the continued and flawless expansion of algorithmic decision-making into more of human reality, making it finally subordinated to the only feasible, relevant chance we will have had: to make ourselves predictable, or to become a non-playable character in the role game of algorithmic prediction.

Concretizing the divinatory faculty of chance into the pseudo-science of risk management (Amoore, 2013) subverts any truly prophetic, oracular, or even simply salient attribute to the predictive power of algorithms –that technocapitalism portrays as the latest concretization of market freedom. In this light the allegedly novel models of governance as a consequence of predictive analytics and algorithmic forecasting seem 'primitive' and 'illusory' –what Stiegler calls "new barbarism" (2019). "Is the state in the age of Deep Mind, Deep Learning, and Deep Dreaming a Deep State™? One in which there is no appeal nor due process against algorithmic decrees and divination?" (Steyerl, 2016). To cut the gordian knot, and to couple 'eloquent' randomness exclusively to the ideal partner of technocapital order, algorithmic governmentality needs some kind of exegetic technique that assure technocapital-bound subjects that their erratic cultural fortunes are in fact completely natural and necessary. That technique is als well a type of omen. Algorithmic divination is the shady, devious public image of a conflicting chimera of markets and machines[174] that tries to confine chance within

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[174] We can understand this as "The Californian Ideology", see: Barbrook, R. and Cameron, A (1996) The Californian Ideology. *Science as Culture*, 6, 1. pp. 44-72; the "Capitalist Realism", see: Fisher, M. (2009) *Capitalist Realism: Is There No Alternative?* London: Zero Books; or more recently, "Platform Capitalism" see: Srnicek, N. (2016) *Platform Capitalism*. Cambridge: Polity Press.

the boundaries of technological determinism: to play a mellifluous mix of noise and financial (dis)order to secure the higher and greater interests of capital at any cost.

Now it is time to move the focus to ourselves and examine the ethical and political dimensions of the relations between human cognition and digital cognitive artefacts, examining a particular coupling between humans and digital cognitive artefacts: interaction-dominance.

Chapter 5: The Over-Extended Mind? Pink Noise and the Ethics of Interaction-dominant Systems[175]

> Labour appears, rather, merely as a conscious organ, scattered among the individual living workers at numerous points in the mechanical system; subsumed under the total process of the machinery itself, as itself only a link in the system, whose unity exists not in the living workers, but rather in the living active machinery, which confronts his individual, insignificant doings as a mighty organism. (Marx, 1993: 693)

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[175] An earlier version of this chapter was co-authored with Darian Meacham and published in 2018, NanoEthics volume 12. pp. 269–281. [online] Available from: https://link.springer.com/article/10.1007/s11569-018-0325-x [Accessed 10 September 2020]

> The individual becomes the mere spectator of the results of the functioning of the machines, or the one who is responsible for the organization of technical ensembles putting the machines to work. (Simondon, 2017: 132)

5.1: Introduction to the Chapter

There is growing recognition in the literature on cognitive enhancement and neuroethics of the need for greater attention to the role of cognitive artefacts in the technological intervention into and alteration of cognitive processes. Fasoli (2016) has argued for the need for greater consideration of cognitive artefacts in neuroethics and has developed a taxonomy of relationships between these artificial devices and the mental processes by which we gain knowledge and comprehension (Fasoli and Carrera 2014). Likewise, Heersmink (2017b) has argued for the broadening of neuroethics and cognitive enhancement debates to include more consideration of emerging technologies such as transcranial stimulation and neuroprosthetics (e.g. Brenninkmeijer & Zwart 2016) but also greater reflection on "environmental objects and structures". Heersmink (2015) has also developed a multi-dimensional framework for conceptualising integration between these 'tools of thought' and human agents. The broadening and greater inclusivity of these descriptive and normative debates to consider a broad range of enhancement technologies have been motivated by developments in what can broadly be referred to as 4E (embodied, embedded, extended, enactive) approaches to cognition (see, for example, [8, 9]). Subsequently, this has furthered the encounter between the debates in the area of cognitive enhancement and those in 4E cognition (see, for example, Menary 2010a, 2010b). In short, if some or all cognitive artefacts are considered forms of enhancement technology, then the form of cognition at issue falls within the domain of 4E approaches. My aim here is to contribute to this discussion and the encounter between these two fields.

There remains however a lack of sustained engagement both concerning the epistemology of cognitive artefacts in the enhancement debate, and the potential ethical and political challenges arising from the increasing pervasiveness of digital cognitive artefacts (see, for example, Meacham 2017) in the fields of 4E (or situated) cognition. It seems clear that discussions of enhancement and cognitive enhancement in particular will increasingly centre around hybrid, human-artefact, cognitive systems, and specifically human + digital cognitive artefact systems[176]. Prospective technologies and scenarios for human cognitive enhancement increasingly implicate hybrids of organic cognitive systems (brains) and digital cognitive artefacts (digital technologies), sometimes called cognitive computing[177].

The world's largest edu-business, Pearson (Williamson, 2016), one of the world's largest computing companies, IBM (Williamson, 2017), Facebook, Amazon, Google, and Microsoft[178] have shown strong interest in the development and production of cognitive computing systems applications for use in the educational market, business, government, healthcare, education, and other sectors. On the basis of these interests, there is a common vision of how machine intelligence might perform as cognitive-enhancement technology in various settings.

Consequently, addressing the epistemological as well as ethical and political questions issuing from cognitive artefacts is one of the most important tasks for the debates concerning responsible research and innovation (RRI) in human enhancement technologies. This, more specifically, is how we hope to contribute to the encounter between discussions in cognitive enhancement and those in 4E cognition. RRI is defined by the European Commission as an "approach that anticipates and assesses potential implications and societal expectations with regard to research and innovation, with the aim to foster the design of inclusive and sustainable research and innovation" (European Commission, 2017). It has been adopted as a research and support initiative within large techno-science and innovation funding programmes by many international and national funders including but not limited to the European Commission's €80 billion Horizon2020 Programme, the UK's EPSRC (Engineering and Physical Science Research Council)[179], and the Dutch NWO, where RRI is

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[176] We understand digital cognitive artefacts simply as cognitive artefacts (defined below) that are digital in nature or incorporate digital processes.

[177] Cognitive computing describes technology platforms that combine machine learning, reasoning, natural language processing, speech, vision, human computer interaction, that mimic the functioning of the human brain and help to improve human decision making. See: http://www.predictiveanalyticstoday.com/what-is-cognitive-computing

[178] See: https://www.partnershiponai.org/

[179] "Responsible Innovation is a process that seeks to promote creativity and opportunities for science and innovation that are socially desirable and undertaken in the public interest. Responsible Innovation acknowledges that innovation can raise questions and dilemmas, is often ambiguous in terms of purposes and motivations and unpredictable in terms of impacts, beneficial or otherwise. Responsible Innovation creates spaces and processes to explore these aspects of innovation in an open, inclusive and timely way. This is a collective responsibility, where funders, researchers, stakeholders and the public all have an important role to play. It includes, but goes beyond, considerations of risk and regulation, important though these are." https://epsrc.ukri.org/research/framework/ (last accessed 3 July 2020).

a flagship programme[180]. While each funder defines RRI (or sometimes just RI, i.e. responsible innovation) in a slightly different fashion, there are clear overarching commonalities. There is an expanding literature on this approach bringing societal, ethical and political concerns directly into the research funding and subsequent innovation process(es). These debates, though significant, are outside the scope of this chapter, which nonetheless situates itself within the scope of RRI as broadly defined above (and in the footnotes).

5.2.: Cognitive Coupling

Relations between humans and digital cognitive artefacts can be characterised as cognitive coupling where there is communication or information flow within the coupled system (human-cognitive artefact). The title of this chapter, "the over-extended mind", refers to a phenomenon wherein (1) the cognitive coupling between a human and a cognitive artefact can be described as "interaction-dominant" (a term that we will define below); and (2) the interaction-dominance is ethically and politically significant for how we understand responsibility and agency. The "over-extended mind", we contend, has consequences pertaining to the responsible innovation and value-sensitive design of those cognitive artefacts that could potentially form intraction-dominant systems with human minds and bodies.

Specifically, it will be argued that interaction-dominance as an emergent property of some human-cognitive artefact couplings has ramifications for the attribution of agency and responsibility in a fashion that is not discussed in the existing literature. While the characteristic of interaction-dominance can be manifest in relations with all sorts of cognitive artefacts, we think that the ethical and political salience comes to the fore in the discussion of digital cognitive artefacts that make use of algorithms (processes or sets of rules used in calculations or other problem-solving processes)[181]. Thus, there are specific implications for discussions about responsible innovation or value-sensitive design of digital cognitive artefacts and specifically human-digital cognitive artefact interfaces. Consequently, we argue

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[180] "NWO-MVI maps and facilitates the incorporation of ethical and societal aspects of technological innovations early on in the design process. Our aim? Responsible innovations that enjoy broad support in society." https://www.nwo-mvi.nl/ (last accessed 3 July 2020)

[181] Algorithms can be understood technically as sets of "encoded procedures" that "transform input data into a desired output based on specified calculations" (Gillespie, Boczkowski and Foot: 167). In more general language, an algorithm is the result of 'what is to be done' with 'how it should be done', or rather, 'defining a problem' and 'naming the steps necessary to solve that problem' (Kitchin, 2017: 17). Algorithms, insofar as they assign relevance to sets of data, have a fundamental normative function. We are grateful to Suzanna Kraak (2018) for making this point.

that in view of the potential scenario of the “over-extended mind”, cognitive distance or disruption in the flow of information between certain kinds of cognitive artefact and their human users can be considered a design-virtue and a key element to consider in responsible innovation. To put this another way: building in some forms of noise qua disruption of information flow could be an aspect of value sensitive design in the innovation of human-digital cognitive artefact interfaces. Noise can in some instances be an epistemic virtue. Correspondingly, accessibility, durability, and intensity of information flow, all dimensions of integration between artefact and human agent, can in some cases be undesirables.

Interaction-dominance in human-cognitive artefact couplings or systems is both indicated and constituted by the related phenomenon of “pink noise”: a sub-type of the general concept of noise. Thus, pink noise performs an important heuristic role in identifying and understanding interaction-dominant systems and the over-extended mind phenomenon. To understand the status and role of pink noise, and consequently interaction-dominant systems, we need to first examine how the general concept of noise operates in the loop of interactions which constitutes the flow of information between human and artefacts. This will establish the theoretical groundwork for approaching the ethical and political dimension of relations between human cognition and digital cognitive artefacts. As pink noise is central to the constitution of interaction-dominance and subsequently the over-extended mind, it plays a significant role in the practical, ethical, and political evaluation of coupling relations between humans and cognitive artefacts.

The main body of this chapter will thus focus on characterising interaction-dominance in its relation to pink noise in the context of human-cognitive artefact coupling. We conclude with a further discussion of some of the ethical and political dimensions of interaction-dominant systems, already alluded to above. We situate our discussion of the ethical and political dimensions in the context of ongoing discussion concerning cognitive artefacts and distributed morality (e.g. Floridi 2013, Heersmink 2017b). Thus, one important aspect of what we hope to do here is a kind of translation work from discussions in cognitive science and philosophy of mind to discussions concerning responsible innovation and value-sensitive design.

5.3: The Terms of Engagement

Before proceeding to the analysis of pink noise in its relation to interaction-dominance, it will be helpful to clarify our usage of several key ideas that have already been mentioned above without sufficient elaboration. A *cognitive artefact* is an "artificial device designed to maintain, display or operate upon information" (Norman, 1991: 17) in order to "functionally contribute to the performing of a cognitive task" (Heersmink, 2013: 465). The development of 4E approaches to cognition in the philosophy of mind has reinforced the role of cognitive artefacts in cognitive processes. 4E approaches to cognition emphasise the importance of embodied engagement with the natural, social, and technological milieu as a fundamental aspect of human cognitive processes. There is a rich and growing literature in this field, and while there is a rather wide heterogeneity of approaches, it does not seem unfair to say that there is broad agreement that even our basic cognitive processes are technologically or artefactually mediated, structured, and scaffolded (e.g. Clark & Chalmers 1998; Wheeler 2005; Clark 2008; Menary, 2010). What is often at stake in debates under the umbrella of 4E cognition is the extent or degree to which cognitive processes are extended beyond the body (into the environment) and hence whether it is more appropriate to think of cognition as extending into the external environment, or somewhat less dramatically scaffolded by it. Heersmink (2017) points out that extended cognition should not be thought about in binary all or nothing terms. Rather, he suggests that it is more appropriate to think of a spectrum of extension relating to the "kind and intensity of information flow between agent and scaffold, the accessibility of the scaffold, the durability of the coupling between agent and scaffold" (2017: 433). As I shall explain, *interaction-dominance* represents an extreme end of this spectrum, where the epistemological, functional, and potentially (though not necessarily) phenomenological delineations between agent and artefact (scaffold) are obscured, precisely due to the dominance of interactions between agent and artefact over discrete agglomerated actions or processes. An interaction-dominant system is one where it is not possible to distinguish discrete causal cognitive components from one another because the organisation of the system emerges in the interactions. Consequently, cognition processes pertaining to such couplings should not be analysed as discrete functions of encapsulated molecules, neurons, neural structures, behaviours or other modules without considering their context or mutual interactions.

As it is by now clear, noise is a phenomenon (or set of related phenomena) present in any conceivable information channel (Shannon, 1949b), and consequently in every cognitive process. As a working definition, we can say that noise involves irregularities, interference, and distortions in the communication between the target properties in the environment and the sensory signal as well as in perceptual or cognitive processes. Cognitive relations between humans and cognitive artefacts will thus, de jure, involve noise. In brief: noise is a given in information channels; information channels are involved in all cognitive processes; thus the extension, regardless of robustness and intensity of cognitive processes into cognitive artefacts or other aspects of the built or natural environment, and subsequently an extension of cognitive processes with the aim of enhancing or augmenting them will involve noise.

Noise in cognitive processes originates from at least two sources. Internally, noise emanates from variability, for instance, noise in neural activation, as when neurons trigger differently on two occasions, despite the same relevant initial conditions. Externally, it arises from inadequate environmental conditions, e.g. listening a conversation close to a busy motorway. In this sense, noise refers to “frequent but small fluctuations” (Longo, 2017: 22) which may disturb the achieved stability of a supposed, in this case cognitive, system. A system is considered robust when it resists noise. Arguments in favour of “developmental noise”, “noise-induced order” and “noise-oriented behaviour” maintain that the structural resilience of a system to noise may help individuals or systems gain the ability to adapt to the environment or achieve a higher level of functionality. I think that the role of noise is an under-explored but central dimension to understanding the cognitive, ethical, and eventually social impact of human-artefact coupling. Despite the emerging body of literature concerning digital cognitive artefacts, for example, Heersmink on their taxonomy (2013), dimensions of integration (2014), and metaphysics (2016) and Fasoli’s work on neuroethics (2016), there is no account of how noise might affect new models of technology-mediated cognition. In this chapter I am particularly interested in the role of pink noise (a sub-type of the umbrella concept noise) as both indicating and constituting interaction-dominant human-artefact cognitive systems. To understand the relation between interaction-dominance and pink noise we need to scrutinise how noise operates in the coupling dynamics between human cognizing systems and digital cognitive artefacts that are integrated into and can advance the critique of humanism –and explore, the possibilities of a post-human ethical framework.

The idea that noise plays a salient and constitutive role in this way faces some challenges. A first and fundamental challenge issues from the debate within cognitive science concerning whether the appearance of pink noise does indicate an interaction-dominant system. Second, there is the question of whether the epistemological, ethical, and political questions raised by demonstrating that some cognitive coupling may lead to the emergence of interaction-dominant systems are qualitatively or indeed quantitatively different from questions raised where an interaction-dominant system is not evidenced. I will address this in the final part of the chapter.

Prior to a more detailed consideration of pink noise and interaction-dominant hybrid human-machine systems, it is important to emphasise the fundamental correlation between noise and cognition, and more specifically between noise and the distortion of cognition. We have to understand noise not only as an object of perception and cognition, but as partaking in the process of perception and cognition. Inquiry into distortion of cognitive processes is a necessary part of inquiring into the conditions of possibility of perception and cognition. Any philosophical inquiry into human agency must deal also with the state of indecision and confusion associated with noise. Any epistemological enquiry into the nature of knowledge, finally, must contend with the role of noise as lived ambiguity, indecision and error in communication processes – cognition is one such communication process as it entails the expression and exchange of information. Noise as a central component of the dynamics of all information systems (Czaplicka, Holyst and Sloot 2013) will have a dramatic impact on the manner in which our cognitive processes are technologically mediated. Despite its role as a *de jure* precondition for cognition, an enabling constraint, noise is a term that still carries many negative connotations (unwanted signal, state of disorder or disturbance that does not contain meaningful data or information). These characterizations thus fail to recognise the multi-scale complexity of noise or its intrinsically functional relationship within cognitive, biological, social, political, and economic systems (Wilkins, 2021) as well as inferential reason (as a process of making generalisations based on data while taking into account uncertainty). From our perspective, it is evident that the emergence and increasing pervasiveness of human-machine cognitive hybrids augments the necessity of an analysis of noise in cognitive systems as cognitive processes are increasingly coupled with and are extended into the ever-expanding array of digital technologies and networks (e.g. Sparrow, Lui & Wegner 2011).

I now turn to the role of “pink noise” as constituting and indicating interaction-dominant systems before discussing some potential ethical considerations arising out of the formation of human-digital artefact couplings that can be characterised as interaction-dominant systems and subsequently, the consequences of our analysis for RRI approaches to enhancement via cognitive artefacts.

5.4: Pink Noise and Interaction-Dependent Systems

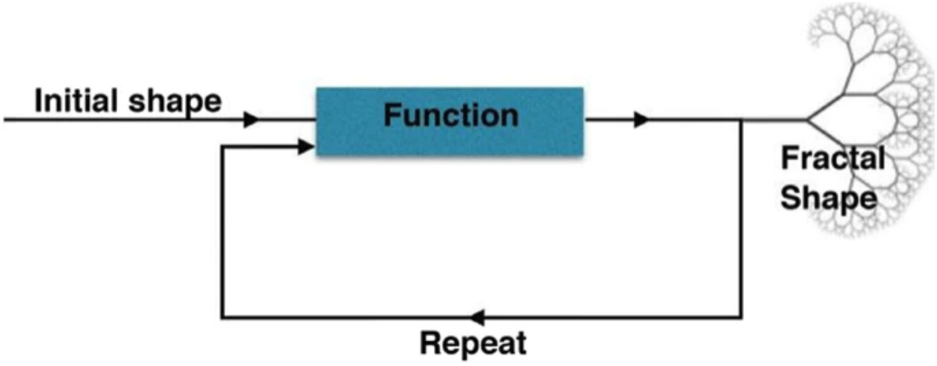
5.4.1: Extended Cognition and Sensory Substitution Devices

It is helpful here to first review the idea of “extended cognition” on which our claims about noise centre. Coarsely put, it is the idea that cognitive systems are extended beyond the boundary of a discrete organism. Cognition is not confined to the limits of our brain, but is attached to embodied sensorimotor processes which are a restraint upon cognition, and not the final limit of cognition. Cognition, subsequently, should be understood as a phenomenon that encompasses processes implicating brain, body, and environment. Moreover, the role of the brain in the process of cognition is not just as a sensory-machine that reacts specifically to certain stimuli or sensory modalities but rather a complex “task-machine” that can, to a degree, re-establish function with input from other senses (Maidenbaum et al., 2014; Murray et al., 2016). This latter aspect is the domain of sensory substitution (SS), where touch or audition, for example, transmit information that is otherwise not available, due, for example, to a visual impairment. Sensory substitution devices (SSDs) have been available for a long time. A blind person’s cane, for example, translates environmental structure into haptic and proprioceptive feedback and sign language translates visual stimuli into language. There are numerous experiments testing if SSDs can become part of extended cognitive systems (e.g. Hurley and Noë, 2003; Bach-y-Rita and Kercel, 2003; Dotov, Nie, and Chemero, 2010). These experiments have shown that sensory-substitution devices can indeed become part of extended cognitive systems and, additionally, these artefacts partially constitute the extended cognitive system. To prove this, researchers have looked at the changes in the information flow (between the nervous system and the devices) produced while the participants engaged with their environment during the task (van Orden, Holden, & Turvey, 2003, 2005). These experiments used detrended fluctuation analysis (a method to measure structural information by quantifying the self-similarity of a time series in a system) and produced a signal that can be considered pink noise.

5.4.2: Pink Noise

Pink noise is a type of variability in a data series that is neither random nor predictable, it has a fractal fluctuating structure. We can collect this data series, for example, by an experiment in which the participants have to press a key in response to a signal on a computer screen (Kello et al., 2007). It is possible to measure the time it takes the participant to press the key as a result of noticing the signal (key-press response time), and the time it takes the participant to release the key to return to the waiting stance for the next trial (key-release response time). The two data series (key press and key release) are subjected to spectral analyses that can identify the pink noise in each separate data series. Pink noise is manifest in the inherent residual variability that remains after the average time interval that each participant produces (for each target interval) is removed from each trial series. Consequently, we can say that pink noise is revealed in the structure of the "background noise" of cognitive performance – the inherent variability of a participant's cognition of passing time.

In the case of a cognitive system, the presence of pink noise indicates that the connections between the different parts are highly non-linear; that means small input changes result in counter-intuitively large changes in the output (Ding, Chen, and Kelso, 2002; Holden, van Orden, and Turvey, 2009; van Orden, Holden, and Turvey, 2003, 2005; Riley and Turvey, 2002). Time series of human performances (e.g. reaction time, memory retrieval etc.) expose patterns of variation with a structure based on self-similarity – this means that the shape looks like itself however much you zoom in or out, like Romanesco broccoli. This self-similar property is true for a type of patterns known as fractals. Fractals are termed infinitely complex because the more closely you look at the object, the more complex it appears. In normal geometry, shapes are defined by a set of rules (i.e. triangle: three straight lines that are connected). Fractal geometry also defines shapes by rules, nonetheless these rules are different. In fractal geometry a shape is made in two steps: first by making a rule about how to change a certain shape. This rule is then applied to the shape again and again, ad infinitum. In maths when you change something it is usually called a function. Thus, a *function is applied to a shape recursively*.



In its fractal fluctuating structure, pink noise expresses the iteration of convergent solutions – tending toward the same result – for common functional problems. Like the branching structure of a tree: from the bottom to the top of a tree, branches become thinner in diameter as they become more numerous. That is, a small piece of the tree looks to a certain extent like an entire tree. A large tree is a complex object, but it is formed by repeating a simple process over and over again.

Thanks to its pattern, pink noise illustrates optimal coordination among the components of a cognitive system and the task environment. Pink noise manifests both stability and adaptability, both attributes characteristic for healthy complex systems (Bak, Tang and Wiesenfeld, 1987). Numerous dynamical diseases (diseases that occur due to an abrupt change in the natural rhythms of the body, i.e. cardiac arrhythmia or epilepsy) have as a common form a transition away from healthy fractal variability and toward a loss of complexity in the dynamical unfolding of a system's behaviour across time (Glass and Mackey, 1988). These fractal patterns pop up repeatedly in the natural world: physical, biological and economic systems exhibit pink noise (Press, 1978; Handel & Chung, 1993). Because of this, some researchers describe it as being ubiquitous (Bak, Tang and Wiesenfeld, 1987) and appearing when the components of a system are so firmly integrated with one another that their functions cannot be explained independently. Van Orden et al. (2003) argue that if we can observe the activity of pink noise during the human performance of a list of cognitive tasks, this demonstrates that the cognitive system is fully embodied and includes aspects that are extended to the periphery of the organism.

Fractal dynamics inform us about the coordination of component processes in living systems. In this respect, it is very revealing that the common fractal signature of a healthy functioning system is found extensively in natural systems that self-organise their behaviour. Self-organisation requires a specific type of interaction to coordinate the processes that must perform together. The correct form of this interaction equipoises competitive and cooperative processes to produce an adaptive and flexible functional configuration or critical state, hence the scientific term “extended criticality”. The interaction that leads to critical states has been calculated for simple physical systems but it is also valid for a working hypothesis for more complex biological and cognitive behaviour. The name for this kind of interaction among component processes is interaction-dominant dynamics. The key fact of interaction-dominant dynamics is that system components change each other’s dynamics to coordinate their collective behaviour (Jensen, 1998) to the extent that delineation between functional components is not rigid but rather characterised by its plasticity.

Following from the previous two sub-sections it is clear that coupling between human perceiver and artefact in the case of some sensory-substitution devices can be constitutive of the pink noise (in the analysis of information flow in the coupling relation) that is indicative of interaction-dominant systems. The next sub-section will show that this relation applies to a wider class of human-cognitive artefact relations, including digital artefacts and human-machine interfaces.

5.5: Computer mouse experiments

Dotov, Nie, and Chemero (2010) have shown that cognitive systems can be made to extend beyond the outer limits of the organism to include digital artefacts in a manner that can be characterised as interaction-dominant. In their experiments, the participants played a simple video game that involved controlling an object on a computer screen using a computer mouse. At random moments during one-minute trials, the connection between the mouse and the object it controls was interrupted momentarily before returning to normal. While the mouse was operating normally, they found evidence of pink noise at the computer mouse interface (hand motions followed the mathematical pattern of pink noise), which diminished during the interruption. Using motion-tracking equipment they recorded the three-dimensional trajectory of the hand-tool system (human and interface); the hand motions of the computer mouse exhibited the nested fractal structure of pink noise (formal and statistical self-similarity). This is where the noise is clearly[182] manifest: at the interface of body and tool (ibid.), because “Pink [1/f] noise cannot be encapsulated; it is not the product of a particular

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[182] Even though this is just one of the places in the system where it is manifest, this is the easiest one to measure, to identify as such.

component of the mind or body." (van Orden, Holden and Turvey, 2003: 345). Dotov et al. (2010) applied an analysis that has been used to establish long-range correlations in the time series which are expressed as pink noise: these long-range correlations stand for long-term dependencies in a signal between the present observation and a large set of previous observations. Thus, the presence of long-range correlations implies the presence of multiple, nested timescales in the system, responsible for the emergence of patterns in the system. Additionally, Dotov et al. (2017) also prepared the experiment to measure physical indicators of stress, such as respiration rate, heart rate, and galvanic skin response (changes in the electrical activity of the skin triggered by emotional or physiological responses). They found an increase in all three at precisely the same moment when the mathematical pattern transitioned from pink noise to chaos.

This shows that, under optimal connection, the computer mouse (a digital cognitive artefact comprising a human-machine interface) is part of the smooth functioning interaction-dominant system involved in the task and that during the mouse disruption the pink noise at the computer mouse interface decreases momentarily, pointing out that the mouse is no longer part of the extended interaction-dominant system. Interaction-dominant dynamics (Anderson, Richardson and Chemero, 2012) express the plasticity of the system's elements and of the communication modes among these elements. Coordinated processes (like the use of a computer mouse to point at something) can alter the integrative action of components to the extent that it is hard, and sometimes unfeasible, to assign tightly defined and unique roles to specific elements. An interaction-dominant system entails that any singular component of the system interacts through the system as a whole, remodelling the dynamics of the other components and overriding the dynamics that the components would exhibit separately. In interaction-dominant systems we cannot treat the components of the system in isolation. Because of the extensive feedback in interaction-dominant systems, one cannot isolate any one component to determine with exactitude what function it has in relation to a particular behaviour. Since interactions dominate, organisation is emergent and depends on the context. The parts that constitute the system arrange themselves according to the current demands of context and perform functions according to this. That is: components can flexibly tie together or split to befit the changing conditions for a given task (Kay, 1988). Thus, organisation in an interaction-dominant system is an emergent coordination, and instead of responding to local divisions and parts, this coordination emerges in accordance with ongoing changes in information flow (Kelso, 1995). Because of these ongoing changes, the behaviour of the components in any particular interaction-dominant system is not predictable from their behaviour in isolation or from their behaviour in some other interaction-dominant system. In other words, interaction-dominant systems are not modular in their design nor in terms of “modular cognitive architecture”; they are in a deep way unified in that the accountability for the system behaviour is scattered across all of the components.

5.6: The ready-to-hand computer mouse

As a result of changing the focus of attention from the information flow to the presence of pink noise, van Orden et al. (2003) argued that the participant-computer system formed an interaction-dominant system, and also provided some empirical confirmation for an aspect of Heidegger’s transition from present-at-hand to ready-to-hand modes of experience (Heidegger, 1962). Present-at-hand refers to our theoretical understanding of a world constituted of objects as standing apart from or against the subject or agent; it is a mode of comprehension. But with the “ready-to-hand” notion of experience, Heidegger argued that people do not notice familiar, functional tools, but instead they “see through” them to a task at hand, for precisely the same reasons that one does not think of the way that one’s fingers hold the pen while writing. *The tools are us*. Similarly, proponents of extended cognition have argued that the artefacts into which cognition is extended must be functionally transparent to the agent (Heersmink, 2017a), they must be used without the agent actively thinking about what they are doing, i.e. how they are using the artefact or incorporating it into their cognitive or motile processes. The distinction that this builds is between an artefact rendered transparent and integrated into cognitive or motile processes and an object that is conspicuous and “stands against” the controlling agent. “Standing against” does not necessarily imply a hostile relationship, it is a general term used in the phenomenological literature for the epistemological-experienced status of objects in the world vis-à-vis the subject, but it does imply an experienced distance between subject or agent and object.

The French philosopher Merleau-Ponty (1945) built upon this analysis to argue that bodily prosthetics, like a walking cane, are, with use, integrated into what he called the “body schema”, an integrated system of bodily motile possibilities functioning both at the level of unconscious sensorimotor processes and consciously experienced movement. From the perspective of both passive (ones we are not aware of) and active (ones we are) conscious processes, the prosthesis becomes part of the body schema. This form of interaction-dominant coupling could be interrupted if for example the stick was accidentally dropped or struck from the hand, returning it to its phenomenological status of conspicuous external object. The discussion of digital artefacts that I engage in here proceeds on much the same grounds. What differs are the descriptive mechanisms for demonstrating the interaction-dominant character of the coupling.

Returning to the experimental setting, when the computer mouse was controlling correctly the on-monitor pointer, the participants experienced their control of the object in the video game, they could see through the tool to focus on the task they were performing, the *presence* of pink noise was *evident* and the computer mouse was experienced as *ready-to-hand*. When the connection between mouse movements and the on-screen control of the object was perturbed, the participants were concerned about the performance of the mouse, they were no longer able to see through the malfunctioning tool, there is *no presence* of pink noise and they experienced it as *present-to-hand*. The phenomenological accounts of ready-to-handedness or prosthetic integration into the body schema are equally applicable here in the case of a digital artefact and accompany the presence and absence of pink noise in the analysis of information flow.

The phenomenological accounts developed by Heidegger (1927/1962) and Merleau-Ponty (1945/1962) are also significant because they bring to the fore several important characteristics of interaction-dominant systems. The accounts of "ready-to-hand" tools and prostheses integrated in body schemata do assume a central subjective controller, an agent whose intentional relations with the surrounding world drive the processes in question, even if biases can be built into artefacts that condition their usage and potential integration into a body schema. Philosophers of technology have pointed out that artefacts are not value-neutral but have affordances and indeed values built into their design. These embedded histories may or may not be apparent to the designers themselves, but often – one can imagine examples where this is not the case, such as when an artefact is transferred outside of its originally intended use context, in play for example – condition the use of the artefact, undermining any claims to absolute sovereignty on the part of a central controlling-acting agent. Nonetheless, the phenomenological example brings to the fore the question of agency in interaction-dominant systems. Closely linked to the question of agency is the issue of passivity in the emergence of interaction-dominance. In both the example of the ready-to-hand tool and the prosthesis that has been incorporated into the body schema, the integration into cognitive and motile processes happens in a manner that is termed passive, or not fully present to consciousness. In other words, the agent or subject is not consciously aware (in the way that we normally use the term) of the full integration of the artefact into its cognitive and motile processes. In fact, as many phenomenologists like to point out, when conscious attention is turned to the relation between the body and the artefact the integration is broken and the artefact appears suddenly conspicuous and often unwieldy. What we wish to argue is that in some settings this conspicuousness, which can also be characterised as or via the concept of noise, qua disruption of information flow, can be an epistemic and ethical virtue.

5.7: Pink noise as the evidence of an extended cognitive system

The presence of pink noise during the performance of human-artefact coupling as demonstrative and constitutive of an extended and interaction-dominant cognitive system, where the device is not merely causally related to the system but is constitutive of the system as such illustrates the relevance of noise, and specifically the subtype pink noise, to an understanding of cognitive processes. This, along with the significant amount of methodology from complex systems theory that is being brought into cognitive sciences, provides good reason to doubt some of the methodological truisms that cognitive sciences students are commonly taught, namely that a good experimental design in the cognitive sciences looks for the minimization of error variance (noise). A significant amount of nonlinear dynamical modelling techniques refute this conception by taking the structure of noise to be the primary data, as we do here. We understand data as the outcomes of observations, measurements, and procedures that the scientists carry out. Quite often these outcomes will be measures of fluctuations (as signals depending on the theoretical framework), which is fundamentally noise.

In cases like the experiments by van Orden et al. (2003) and Anderson et al. (2012), noise no longer should be received as meaningless fluctuations that can be overlooked or ignored as second order data, nor confused as uncertainty. Precisely because here, *pink noise is the evidence* (at the core of the system) that humans and computers together can comprise unified interaction-dominant systems: pink noise designates a unified system of parts. It is important to emphasise the temporal dimension of interaction-dominance alongside the functional indiscernibility of causal components within an interaction-dominant system. Chemero (2003, 2011) very often gives the example of walking. When we walk on a level path, our stride length will appear to be mostly the same, but there are subtle variations. These variations create a system that has a “long memory”. It is the very same long memory processes with long-term correlations that exhibit pink noise fluctuations. The way we walked twenty paces ago affects the pace we are about to take. If the system were not interconnected in the way that it is, it would show randomness. Pink noise is neither regular nor random; it is an irregular, fractal pattern that resembles itself on large and small scales and stands for a system whose parts interact densely in real time.[183]

5.8: The Many Virtues of Noise: Heuristic, Epistemic and Ethical

Let me return briefly to the key aspect of the summary definition of interaction-dominant systems: This entails that any singular component of the system interacts through the system as a whole, remodelling the dynamics of the other components and overriding the dynamics that the components would exhibit separately. The result is a functional and temporal indiscernibility and plasticity of causal components in an interaction-dominant system. The experiments discussed in the previous section demonstrate that the emergence of such systems is possible under quite routine conditions. My contention here is that interaction-dominant systems, as emergent but common occurrences, can, by the fact that they do not consist of discernible causal, temporal or functional components, complicate or render impossible the assignment of agency or potentially responsibility as well as our understanding of autonomy in ever more prevalent human-digital artefact couplings. This is in part illustrated by several counter examples. Recall the previous example of a walking stick used as a sensory substitution device being integrated in the body schema of an agent to an extent that when in use an interaction-dominant system emerges. The light-weight stick may offer affordances (Chemero, 2003) (I understand affordance here in a very basic sense as a perceptually manifest possibility of an object for action in an environment) for more nefarious use, for example thwacking others on the street. In such cases, despite the existence of an interaction-dominant system having emerged, the assignment of agency and responsibility for the action is not in doubt. Though the intensity of the extension is such that functional delimiting of parts is not possible, there remains little doubt of a central, subjective

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[183] Thornton and Gilden (2005) and Torre and Wagenmakers (2009) argued that 1/f-like scaling might result from a component-dominant system – components which interact in sequence as in a machine, rather than an interaction-dominant system. Recently, however, Ihlen and Vereijken (2010) have shown that the presence of multifractality demonstrates definitively that a system is interaction dominant. Ihlen and Vereijken reanalysed the data from van Orden et al (2003), and showed that it is multifractal.

in this case, controller who is the agent of the action and hence the potential subject of responsibility. When the coupled artefact makes use of algorithms for problem solving, the situation may be different. It is helpful here to parse the discussion through Floridi's and Sanders' (2013) discussion of distributed morality.

Drawing on theories of distributed cognition wherein a set of cognitive agents has knowledge that no one individual within the set has, Floridi builds an account where a set of morally neutral or negligible acts interact to create a morally salient act as an emergent property of the interaction – when two potentially neutral states or acts interact in the right way the result of the interaction is morally salient. It is important here to understand the salient act in two possible ways: on the one hand, it might be an emergent property of the interaction or it could be the cumulative effect of otherwise below moral salience threshold acts accumulating to pass the threshold of salience. The analysis here is decidedly consequentialist, or "receiver-perspective" since salience is gauged in terms of overall impact on the environment and its inhabitants, not on actor intentions. Such instances of distributed morality can go both ways, i.e. toward positive and negative evaluation. Floridi provides the example of consumer driven corporate responsibility programmes which require a critical mass of participation to become salient.

What distinguishes cases of distributed morality from interaction-dominance? It is certainly possible that distributed cognition or morality networks can be interaction-dominant, but they are not necessarily so. In the examples discussed by Floridi and Sanders (ibid.), the delimiting of discrete causal components and behaviours is possible, responsibility for certain temporal or functional events in the process of a network interaction or process can still be assigned. This is not the case in an interaction-dominant system. We should be careful to remain specific in our understanding of what an interaction-dominant system is and how it is empirically identified, hence the importance of pink noise in this discussion. Heersmink (2017) helpfully contrasts Floridi's distributed morality approach with the more actor-network theory influenced notion of "distributed agency" developed by Verbeek (2011). Verbeek's account confronts what he argues is the non-value-neutrality of certain artefacts in context. It is not so much that values or designers' intentions are embedded in artefacts in a way that directly impacts a morally relevant context, but rather that aspects of technology become value-charged within certain contexts to the extent that it is not possible to say that the artefact is value-neutral as the meaning of its functionality can only appear in a context.

Heersmink, following Verbeek, refers to the example of an ultrasound machine noting that the enlarged size of the imaging, the possibility of discerning gender, in other words, the personification of the foetus via the imagining technology, is not value-neutral and that this can only be assessed in context. Examples such as this may be morally salient, but may still lack the same characteristic of interaction-dominance, namely the specific form of functional integration demonstrated by the appearance of pink noise. The lack of interaction-dominance is significant because the possibility for a clear if not totally transparent delineation of functional causality and competence within a system or network allows for a clearer, if not necessarily transparent, assessment of responsibility.

We can imagine examples where the demonstration of interaction-dominance, particularly in the relation between human and digital cognitive artefacts (artefacts making use of decision making and problem solving rules) has particular significance in assessing responsibility. There are reports of systemic racial bias, *hardwired ideologie*s, in some decision-making algorithms, for example the COMPAS system used to assess the likelihood of recidivism for accused criminals. Speilkamp (2017) summarised the findings of ProPublica (Larsen et al., 2016):

> ProPublica, a Pulitzer Prize winning not-for-profit news organisation, analysed risk assessment software known as COMPAS. It is being used to forecast which criminals are most likely to reoffend. Guided by such forecasts, judges in courtrooms throughout the United States make decisions about the future of defendants and convicts, determining everything from bail amounts to sentences. When ProPublica compared COMPAS's risk assessments for more than 10,000 people arrested in one Florida county with how often those people actually went on to reoffend, it discovered that the algorithm "correctly predicted recidivism for black and white defendants at roughly the same rate." But when the algorithm was wrong, it was wrong in different ways for blacks and whites. Specifically, "blacks are almost twice as likely as whites to be labelled a higher risk but not actually re-offend."

Algorithmic decision making can be biased for a number of reasons, including the fact that often unconscious or implicit biases of those writing the algorithms are built into their rule making structures, or for reasons unknown to engineers because the mechanisms of the algorithm have been blackboxed. In cases such as COMPAS, the digital artefact is supposed to provide guidance to a human decision maker who, in these cases at least, remains the central controlling agent (to use the language of extended cognition). However, if usage of the interface is such that there is evidence of the emergence of an interaction-dominant system the temporal and functional delineation of competencies within the decision making process may be difficult to discern (I introduce this as a hypothetical, not as an actual assessment of the COMPAS system). In situations where such delineations are essential for the possibility of assigning legal or moral responsibility and also for the possibility of appeal due to evidence of bias somewhere in the components of the system, prior to the formation of the interaction-dominant systems (or after the fact) the appearance of pink noise is not only a potentially useful heuristic, but a possible canary in the proverbial mine. I do not mean to suggest that testing for pink noise is a way of overcoming the issues pertaining to the use of automated decision-making systems in the criminal justice system, nor even that bias introduced by the algorithms used by systems such as COMPAS may somehow be worse than unextended (into digital cognitive artefacts) human biases. We could also envision a situation wherein biases embedded in computer algorithms could be corrected for by other computer algorithms. Rather, that pink noise is a potentially helpful and important indicator of interaction-dominant relations, and that the latter may be undesirable in contexts where the identification of functional and temporal causal accountability is considered required *or* evidence that such Cartesian humanist ethical frameworks are not adequate for making moral judgements in interaction-dominant systems. And since such systems are, actually, pretty much universal, pink noise can actually be understood as a measure of the in-human origins of all processes –including apparently ‘human’ processes. Pink noise is a heuristic key to the phenomenon that I called, at the beginning of this chapter, the over-extended mind. Hence, I think that the role of pink noise is potentially important further upstream in the design process and has lessons for the responsible or value-sensitive design and innovation of digital cognitive artefacts for the purposes of cognitive or other forms of enhancement. The over-extended mind and with it the role of pink noise point to the importance of distance and functional demarcation as an epistemic, ethical, and even social-political virtue in the design of interfaces between humans and digital cognitive artefacts. In other words, it points to noise qua disturbance in human-digital artefact coupling as a potential epistemic, ethical and social-political virtue in value-sensitive design. While interaction-dominance can certainly be a virtue in the case of sensory substitution prosthetics (e.g. the walking stick) it is less likely to be so when the coupled artefact has its own decision-making processes and rules that may not be transparent or available to other nodes in the network and when the delineation of functional competence and linear temporal relations is central to the moral, political, or legal evaluation of an action or behaviour. This emphasises, again, the need for post-humanist ethical criteria for judging the ‘virtue’ or otherwise instantiated in various forms that the interaction-dominant networks might take. Cartesian humanist anxiety over autonomy, agency, responsibility and the like, are not the most ‘reasonable’ approaches. The goal of seamless integration with digital artefacts may have unforeseen negative consequences, while distance, disruption of information flow, and distraction, classical noisy enemies of cognition, may turn out to be virtues after all as the extension of morally, legally, and politically salient decision making and behaviours into digital artefacts becomes increasingly pervasive. Thought and reflection, as opposed to cognition, are after all often noisy and make use of resistances and interference to become more adaptive. As we look to digital artefacts to enhance all sorts of capacities, this desirability of distance, demarcation, and even disruption may be worth remembering.

In his seminal paper, ‘Do artifacts have politics?’, Langdon Winner (1980) argued convincingly that they do. A further difficulty emerges when one faces artefacts or technical assemblages that make it increasingly difficult to unravel the politics embedded in them from one’s own. This is a situation that I think is made more likely and more prevalent by the increasing pervasiveness of digital cognitive artefacts and, in some cases, the emergence of ethically salient interaction-dominant systems. In this context, some noise between us and our digital tools may not just help to discern both responsibility as well as, in the case of pink noise, potential issues in assessing certain types of responsibility, but may also be a key indicator in the responsible innovation of human-machine interfaces.

Chapter 6: Noise and Synthetic Biology: How to Deal with Stochasticity?[184]

> Because they behaved with me at random, I will as well behave with them at random.
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> —Leviticus 26:40-41[185]

6.1: Introduction to the Chapter

We have seen in the first chapter how information theory generally understands noise as the opposite of information—be this a physical magnitude or knowledge obtained from data. Nonetheless, noise is also understood as a source of novelty and variation in the biological gene pool. Therefore, within (the novel) synthetic biology research, the use of the term noise often refers to stochastic fluctuations which have a functional status. It is important to understand that the word "stochastic" does not entail that an entire cellular system behaves in an entirely random way; it stands for the impossibility of determining with absolute certainty how the system will evolve from a certain initial state. Even considering events that could be "more probable" than others (depending on the physico-chemical properties of the species involved) the global state of the system will always exhibit a certain degree of unpredictability. The disciplines of information theory, statistical thermodynamics and biochemistry offer sufficient evidence to assert that fluctuations in gene expression are inevitable in biological systems (Lestas, Vinnicombe and Paulsson, 2010); they are the consequence of the intrinsically stochastic nature of molecular interactions. Thus, it is not

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[184] An earlier version of this chapter was published in 2020, NanoEthics volume 14. pp. 113–122. [online] Available from: https://link.springer.com/article/10.1007/s11569-020-00366-4 [Accessed 10 September 2020]

[185] Translated by Henri Atlan, see: Atlan, H. (1995). Comment le dieu biblique peut « aller au hasard » en hébreu mais pas en traduction. Meta: Journal Des Traducteurs, 40(3), p. 508.

surprising that the expression levels of individual proteins are subject to random fluctuations over time.

Shannon’s traditional characterisation of information as the measure of the diminishment of uncertainty does not suffice for the richness of a “biotic system” (Kauffman et al., 2008: 37) that propagates its organisation (or instructional information) by transforming free energy into work. DNA’s information is not riveted like Shannon’s information as the selection of message elements from a set (“selective information” in MacKay’s words (1969: 16)) but it is context-dependant like MacKay’s “structural information” (ibid.). This is in such a way that the same genotypes can bring about different phenotypes depending on the environment or context. Contemporary “teleosemantic” approaches to genetic information were introduced by Sterelny et al. (1996), Maclaurin (1998) and Maynard Smith (2000). These depart from the idea of genes as “carriers of a message”, a message which conveys a prescriptive or imperative content, in contraposition with an indicative or descriptive one. Their “direction of fit” to their goals is so unobjectionable that if the genes and the phenotype mismatch, what we find is an instance of unaccomplished instructions rather than imprecise descriptions.

This notion of information in biology (biotic information) understands that the constraints that make possible the propagation of organisation in a living organism stand for the information content of that organism (Kauffman et al., 2008). Gene expression is a stochastic (or noisy) process, and gene regulation is decisive for adaptation and biological signals processing.

This chapter explores the functional role of noise in synthetic biology and its relation to the concept of randomness. Ongoing developments in the field of synthetic biology are pursuing the re-organisation and control of biological components to make functional devices. This chapter addresses the distinction between noise and randomness in reference to the functional relationships that each may play in the evolution of living and/or synthetic systems. The differentiation between noise and randomness in its constructive role, that is, between noise as a perturbation in routine behaviours and noise as a source of variability that cells may exploit, indicates the need for a clarification and rectification (whenever necessary) of the conflicting uses of the notion of noise in the studies of the so-called noise biology (e.g. Vilar et al. 2002; Rao et al. 2002), developmental noise (e.g. Blomberg, 2006, Lewontin, 2000;

Raser and O'Shea, 2005; Barkai and Shilo, 2007 Kussell et al., 2005) and noise-induced and noise-oriented phenomena (e.g. Meyer and Roeder, 2014).

This chapter will therefore argue that the investigation of the role of the concept of noise in synthetic biology should contain an account of both the structural resilience of a system to noise and an investigation of the functional integration of randomness. The response to this issue is relevant both to techniques used in synthetic biology and to how the field of synthetic biology conceptualises the functional dimensions of the systems that noise is altering or constructing. In the last decade there have been remarkable efforts challenging the problematic misconceptualisation of chance and noise in the form of random fluctuations and perturbations (e.g. Calude and Longo 2016; Bravi and Longo, 2015; Perret and Longo, 2016; or Wilkins, 2020[186]). In what follows, we will cover their progress as we need to provide another account of the phenomenon of noise as it enters a system in many different structural-functional configurations.

6.2: What We Are Talking About when We Talk About Noise and (Synthetic) Biology

Whenever matter is rearranged to create a new information structure, the introduction of an element of chance is needed. Without alternative possibilities, no new information is possible. It seems contradictory that noise, in the form of randomness, can be the paradigm source of variability (or new information), aligning its definition with low or negative entropy — as we have seen in previous chapters, the very opposite of our common understanding of noise as positive entropy. But systems are never sufficient to cancel the relative universality of what is not a system. The informational constraints and boundary conditions are, together with noise, co-determining and co-enabling biological systems. Since quantum level processes bring in noise, information stored may contain errors. When information is recalled, it is again exposed to noise and this may also corrupt the information content. Despite the constant presence of noise inherent to biological systems, this has accumulated and increased their consistent[187] information content over billions of generations. In Monod's words, noise is the "progenitor of evolution in the biosphere and accounts for its unrestricted

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[186] A criticism already outlined by Thom in "Stop Chance! Silence Noise!" (1983) against the work of Monod (1970), Prigogine (1984), Atlan (1972), and Serres (1980).

[187] Please note that I am not talking of physical invariance/stability.

liberty of creation, thanks to the replicative structure of DNA: that registry of chance, that tone-deaf conservatory where the noise is preserved along with the music.” (1970: 116-117).

At first, synthetic biologists considered stochastic gene expression (or noise) an important obstacle to overcome. Nowadays, it has arguably become one of the main insights contributed by the discipline, since it reconstructs our comprehension of *why*, *how* and *when* specific genes are expressed. However, it is not clear yet how cells actually manage to deal with random outcomes in their expression, and how they achieve robustness. To what extent is noise expression tolerable? Is it relatively harmless, or can it lead to adverse consequences? If cells can actually use their internal noise to cope with the external noise of an unpredictable environment (Eldar and Elowitz, 2010), does it mean that cells have adapted (in the course of evolution) to cope with or (perhaps much more interesting) to take advantage of and to be optimised to function in the presence of stochastic fluctuations?

6.2: Case Studies on Noise and Synthetic Biology

The landmark characterisation of stochastic gene expression was carried out in the field of synthetic biology. In their experiments, researchers found noisy behaviour in gene expression, interfering with the operation of engineered genetic circuits. This is the case of one of the first practical examples of synthetic biology: the *Repressilator* (Elowitz and Leibler, 2000). The fluctuations they found involve non-linear feedback mechanisms that lead to complex behaviours. The Repressilator is a circular system of three genes, arranged in a feedback loop that results in oscillatory behaviour and in which products sequentially inhibit the expression of the next gene. Elowitz and Leibler discovered that the oscillations were ruled by marked fluctuations in their period and magnitude and hypothesised that stochastic behaviour in gene expression was responsible for these effects. It is important to add that the stochastic fluctuations found in the Repressilator were in fact unwanted perturbations, muddling deterministic behaviour. What is interesting is how it triggered the enquiry to modify the design of the Repressilator in order to achieve more robust behaviour. Particularly fascinating for the researchers was the question of whether the stochastic fluctuations they detected could also perform a functional role. In later research within synthetic biology, noise based on stochastic fluctuations gained a functional status (Knuuttila and Loettgers, 2011). In another experiment (unequivocally oriented towards the control of fluctuations) Becskei and Serrano (2000) demonstrated that engineering a circuit with negative feedback could decrease cell-to-cell variability in expression. The process of pattern formation in living systems is also of capital interest to synthetic biologists attempting to develop living tissue in the laboratory. Synthesised tissues could have innumerable potential medical applications, but in order to engineer living tissues, researchers need to understand the genesis of pattern formation in living systems. Recently, Karig et al. (2018) engineered bacteria that, when incubated and grown, exhibited stochastic Turing patterns. It is the first in vivo proof of the principle that patterns can be stabilised by noise (University of Illinois College of Engineering, 2018). Turing patterns can be spots, stripes or spirals that arise naturally in a species. In 1952, Turing's groundbreaking paper "The chemical basis of morphogenesis" provided a theory for the formation of patterns in systems undergoing reaction and diffusion of their ingredients; this is the so-called a *reaction–diffusion theory of morphogenesis*: stationary chemical patterns can be achieved from a system of two different interacting molecules (called morphogens) if they have specific characteristics (Turing, 1952). One is an "activator", which is autocatalytic and so introduces positive feedback. The other is an "inhibitor", which represses the autocatalysis of the activator, and so enhances negative feedback. It is essential that they have different rates of diffusion: the inhibitor must be faster. Turing patterns were originally observed in some specific chemical reactions, but such patterns have proven very difficult to verify in biological systems. Goldenfeld explains that the problem with Turing's mechanism is:

> that it hinges on a criterion that isn't satisfied in many biological systems, namely that the inhibitor must be able to move much more quickly than the activator. For example, if instead of chemicals, we were looking at two creatures in an ecosystem, like wolves and sheep, the wolves would need be able to move around much faster than the sheep to get classic Turing patterns. What this would look like, you would first see the sheep grow in number, feeding the wolves, which would then also grow in number. And the wolves would run around and contain the sheep, so that you would get little localized patches of sheep with the wolves on the outside. That's essentially the mechanism in animal terms for what Turing discovered. (2018)

In their recent research, Karig et al. (2018) devised a theory of stochastic Turing patterns, wherein patterns develop from the noise of stochastic gene expression instead of relying on a high inhibitor–activator ratio. The researchers used synthetic biology to engineer bacteria, based on the activation–inhibition idea from Turing. They built a maximally exhaustive stochastic model of the process occurring in these synthetic pattern-forming gene circuits, and they established a comparison between the theoretical predictions with what the bioengineers observed in the petri dishes. Resorting again to the analogy of wolves and sheep, Goldenfeld addresses the issue of the speed difference between the activator and the inhibitor by asking:

> what happens if there is only a small number of sheep, so that there are large fluctuations in population numbers? Now you get processes where sheep die at random. And we discovered, when you give birth to randomness, that actually drives the formation of stochastic Turing patterns. […] The theory of stochastic Turing patterns doesn't require a great difference in speed between the prey and the predator, the activator and the inhibitor. They can be more or less the same, and you still get a pattern. But it won't be a regular pattern. It'll be disordered in some way. (2018)

Turing patterns can in fact be achieved even in situations where you would not expect to be able to observe them, but they are disordered patterns—stochastic Turing patterns. Noise causes the formation of transient, stochastic Turing patterns for parameter values in which deterministic patterns do not form. In this case, it is the noise of stochastic gene expression that originated these patterns. These results show that Turing-type pattern-forming mechanisms, if driven by stochasticity, can potentially underlie a broad range of biological patterns –presenting another example of noxiogenesis. These experiments provide the groundwork for a unified portrait of biological morphogenesis, emerging from the compound of stochastic gene expression and dynamical instabilities.

Even though these different research projects confirmed that noise in gene expression is important and could even be controlled, the molecular basis for the perceived variability remained unclear. Elowitz et al. (2002) and Ozbudak et al. (2002) were the pioneers exploring the reasons behind stochastic gene expression.

6.2.1: Distinction Between Intrinsic/Extrinsic Noise and Stochastic Pulsing

Elowitz et al. introduced the concepts of *extrinsic* and *intrinsic* noise in gene expression (analysed mathematically by Swain et al., 2002). The overall variability in gene expression within an isogenic population (those characterised by substantially identical genes) is described by biological noise. The gene expression in these populations is not consistent from cell-to-cell, even in cases of populations with a stable average expression level or steady-state. This occurs because of the variations in "'hardware' units, such as transcriptional–translational machinery and regulatory molecules (resulting in extrinsic noise), as well as the inherent stochasticity attributed to the random nature of single-molecule kinetics (resulting in intrinsic noise)." (Ciechonska, Grob and Isalan, 2016: 384). These are the two principal typologies of biological noise that have been defined within the realm of systems biology. These two kinds of noise highly enrich the phenotypic heterogeneity of genetically identical populations.

According to Elowitz et al. (2002) *extrinsic* noise in gene expression is caused by cell-to-cell differences. These differences between cells, whether in local environment or in the concentration or activity of any condition that influences gene expression, will cause extrinsic noise. This entails the fluctuations in the volume or activity of molecules such as the proteins that influence the regions of DNA or the enzymes that synthesise DNA, which in turn produce subsequent fluctuations in the output of the gene. These fluctuations are regarded as sources of *extrinsic* noise that are global to a single cell but deviate from one cell to another. That is to say, extrinsic noise constitutes evidence that a cell is not an autonomous thing; it is ingrained in an organism and sustains links with it by integration and regulation mechanisms in various directions.

On the other hand, *intrinsic* noise refers to the stochastic fluctuations within the system being considered. Generally, they are the product of the inherently probabilistic nature of the underlying biochemical reactions. In other words, it is called intrinsic noise as it originates from the very nature of elements of the systems and not from external disturbances. Determined by the structure, reaction rates, and species concentrations of the underlying biochemical networks, biological intrinsic noise is directly correlated to the expression of a single gene. The reason for this noise is the fact that all transcription and translation events have their origin in stochastic collisions between the components of the transcription and translation machinery of each gene. Thus, the same gene will almost never be expressed in the exact same way in two different cells.

Noise-dependence is also a key factor in the dynamic cell reactions to varying environmental conditions. Living organisms respond and react to changes in their environment. They do so by decoding the information contained in these changes; this entails stochastic pulses in activation and deactivation of regulatory factors within a population. Negative and positive feedback are characteristic kinds of regulation in genetic networks. Stochastic pulsing is the result of the interaction between the positive and negative feedback loops of such systems (Bernardo and Dunlop, 2013, where the negative feedback loop produces pulses and the positive feedback loop serves to amplify them. Additionally, the fluctuations arising out of noise appear to be an intrinsic attribute of gene expression, as can be noticeable in artificial cells made up of cell membrane-mimetic vesicles. Synthetic biology needs a proper understanding of cellular noise—considering that its goal is to engineer gene circuits with well-defined functional properties. We gain understanding about the regulatory mechanisms that tune biological noise in natural networks from the application of synthetic biology tools in the research of the diverse components of stochasticity, via the analysis, control and exploitation of biological noise (e.g. Eldar and Elowitz, 2010; Ciechonska, Grob and Isalan, 2016). If noise can be a positive, enhancing factor in a system's robustness, this could support the design of innovative synthetic devices, with potential benefits in multiple fields around biotechnology.

6.3: The "Information Metaphor Falsehood" and the Glorification of Noise

Both the field of epistemology (Loettgers, 2009; Knuuttila and Loettgers, 2011, 2014) as well as philosophy of biology (Calude and Longo, 2016; Longo, 2017; Bravi and Longo, 2015; Perret and Longo, 2016) have recently raised concerns about the dominance of reductionism in the field of biology, and in particular biological engineering. Stressing as well a problem of nomenclature, when from these disciplines, we see examples of what is called noise that in fact might be randomness playing a positive role for an organism. This would conform to an image of biological phenomena which match up with physical explanations (Perret and Longo, 2016), so there is a reduction of the theories of the special sciences to fundamental physical theories. Epistemic reductionism would assume that even complex systems share the same basic processes which are mechanistic, and could be understood in terms of the behaviour of micro-physical entities.

In a gesture against this epistemic reductionism Perret and Longo (2016: 1) state:

> [T]he adoption of information in biology is an erroneous transposition from a specific mathematical domain to one where it does not belong. Indeed, the mathematical framework of the information theory is too rigid and discrete to fit with biological phenomena. Therefore, information in biology represents an inappropriate metaphor.

They maintain that the breeding ground for our current Information Age is the theory of the elaboration of information (Turing-Kolmogorov) (Turing, 1936) and the theory of the transmission of information (Shannon-Brillouin) (Brillouin, 1962; Shannon, 1948), both based on computing discrete values, but wrongly assuming the "independence of the encoding from its material embodiment" (Perret and Longo, 2016: 3). They state that there is no discrete informational value for any part of a biological system but, on the contrary, only a context-specific *meaning*. They elaborate a critique of the current trend in genetics which is characterised by a "central dogma" circumscribed by a "genocentric view of DNA" (Wilkins 2021) which considers the process of gene expression as a unidirectional flow of information. This has the result that any other variables are understood and processed as noise, and any unpredictable outcomes are understood and processed as results of noise. Such a use of the concept in Longo's view is an illegitimate and misleading overextension of the term "noise". They find an example of this in Monod's well known statement: "[F]rom a source of noise natural selection alone and unaided could have drawn all the music of the biosphere." (1970: 118).

We cannot argue against the evidence that a computer (Turing) or a cable (Shannon) implies material determinations that differ fundamentally from the continuous dynamics that take place in the morphological constitution of a biological organism. Perret and Longo rightly warn that applying the mathematical framework of the information theory entails a theoretical account of Laplacian predictability "that opposes determination to noise and that is largely superseded, even in classical physics, by the modern theory of dynamical systems […]. [A]pplying information theory to biology is not free from the attitude that tries to reduce complex biological systems to deterministic systems" (Perret and Longo, 2016: 5). However, the allegation of a scientifically erroneous exportation of theories of elaboration and transmission of information to biology (as a gesture of methodological reductionism) fails to acknowledge that it is not the case that applying the metaphor of computation/information to biology is wrong. Rather what is wrong is the image of computation/information that was applied. This is because what constitutes information is locally determined by the process of which its epistemic metarepresentation forms part. Information can never be meaningfully considered in isolation; it must always be seen in the context of its language processing system and the work module that this is in turn connected with (and this is the reason that for Shannon information is an inadequate measure of biological information). As Wilkins (2021) explains, Perret and Longo argue that in opposition to reductionist and deterministic images of biological processes as composed of generic particles and discrete data points, we should make a case for the *specificity* of the material arrangement of living systems. Instead of understanding biological systems as "noise-immunised informational processes, the 'default state' of the living (on analogy with Galileo's principle of inertia) should be understood as (random) variability" (ibid.), and biological organisation as the sustainment and dissemination of materially specific constraints which render that randomness, so that any element of the system does not contain a discrete informational value but a context specific meaning.

According to Longo (Bravi and Longo, 2015), a system is robust when it resists noise. This is particularly true of living systems, where randomness has a functional role that contributes (in an essential way) to the structural stability of system dynamics. Random mutation and copying errors in genetic replication have also been theorised as noise; however, Longo et al. argue that this kind of variability is so functional in biological evolution that describing it as noise is a spurious scientific characterisation. Longo understands that noise refers to small (and frequent) fluctuations (2018) in general, which may actually disturb the achieved stability of a biological system. He argues that we should not call these intrinsically random aspects of onto-phylogenesis (Bravi and Longo, 2015), *noise*, but rather consider them indispensable components of stable biological complexity. For him, randomness is so intrinsic to the evolutionary stability of those systems that it can be argued there is no noise for such systems. Noise is recognised by Longo as an information-theoretic notion, totally unsuitable for theorising in the realm of biology. Moreover, he maintains that if there is a productive role for noise, we should replace the term "noise" with another concept that would also encapsulate randomness and model deviation as playing a functional role by stimulating variability and diversity. But is this use of the notion of randomness in the organisation of information an instance of the functionality of noise?

In order to proceed with this clarification, I will first develop an ultimately problematic idea initially articulated by Thom (1983, 1994): randomness and noise are relative to the specification of a scale and language for analysis. I argue that Thom's understanding of noise as subjective or belonging only to the process of conceptualisation functions as a productive argumentative foil through which to rehabilitate noise as a concept applicable to certain cases emerging from (synthetic) biology. Thom's approach, which stands in explicit contrast to Darwinism, thus remains fruitful if we understand it beyond the scope of his Laplacian Worldview.

Central to Thom's argument is a critique of Darwin's notion of "descent with modification" (1859: 171) for making "an illegitimate use of chance" (Thom, 1994: 12). Darwin's principle is premised on the "extreme sensitivity" (1859, chapter 5) of biological dynamics to minor changes in external and internal conditions. For Darwin, random variation or noise is at the core of variability and diversity production in evolution, which makes selection and, actually, life possible (and understandable). Thom extended this critique of Darwin to Prigogine, Monod and other "fetishists" of noise. Thom's counter-argument is that noise is in our process of conceptualisation. Moreover, he explicitly claims (as it was advanced in the first two chapters) that intelligibility cannot include randomness as an intrinsic component of the analysis of a system's dynamics. He maintains that "the signal-noise distinction is then fundamentally subjective" (1994: 20).

6.4: Where Is Noise Located?

> I saw the earth in the Aleph and in the earth the Aleph once more and the earth in the Aleph… (Borges 1949: 151)

Thom's position runs counter to the understanding of randomness and noise I wish to argue for. Contra Thom and Prigogine, Longo contends that randomness is neither in nature (Prigogine) nor exclusively in the theories that we use to talk about nature (Thom). Rather, Longo argues it is in the *interface* between our theoretical proposals and reality, which is whatever we may access by measurement and by measurement only (Calude and Longo, 2016). That is, Longo considers that randomness appears as a result of measurement. Measurement is understood by him as the classical and quantum interface between our human computational models and the world, and is either treated as epistemic (typically, we expect causes for the fluctuations) or intrinsic to the theory—quantum mechanics contemplates some acausal phenomena found at measurement. According to this, Longo (personal communication, 2018) sees randomness located at the interface, where measurement, by various a priori principles grounding each theory, is either indeterminate or approximate.

As maintained in the field of endophysics[188], scientists are engaged in the world they are studying and aspiring to understand. Since this is, at the end of the day, inevitable, knowledge of systems from the inside needs to be understood as more fundamental than "external" knowledge of systems – reality is ascribable to an *interface* between an observer and *the rest of the world* (Kampis and Weibel, 1993).

If noise and stochastic processes are closely linked together and all processes in nature are fundamentally stochastic (Tsimring, 2014), where would this interface credibly lie? Stochastic processes are frequently neglected in the macroscopic world due to the law of large numbers, which states that a given random operation, provided some initial constraints, will tend to even out towards an average result the higher its number of iterations. While this is understandable for systems at equilibrium, where the relative magnitude of fluctuations for a system with N degrees of freedom scales as 1/√N, the central limit theorem does not always apply (ibid.). Biology deals with living systems that are manifestly non-equilibrium, and even macroscopic systems can exhibit anomalously large fluctuations (Keizer, 1987). But we could argue that randomness is only at the interface when made relative to a particular information processing model. Such a model, as regards its distribution of subjective and objective constituents, can be considered an epistemic truth because it is relative to measurement and the capacity of an information-processing agent to predict, but this does not entail a denial of its ontological status—a process/event/object has an objective degree of randomness for any computational system relative to its computational power. As we have seen in chapter 2, there are various measures of randomness/complexity that are objective because they are true for any information processing system, such as Chaitin-Kolmogorov complexity (Chaitin, 1966; Kolmogorov, 1968; 1983). Once again, Kolmogorov complexity theory or algorithmic information theory states the minimum amount of information you need to replicate a given signal. The shortest length description gets the picture about the objective degree of randomness of a sequence/object, but the randomness

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[188] Understood as a framework for organizing an internalist perspective on the world within science (Rössler, 1998).

still is relative to the information processing system and comes into view, at the interface between the observer and the sequence/object. We can draw a parallel between this and the problem of the ontological status of information: the world is informational but you need information processing for information to exist. Is it credible to make any sort of distinction between a theoretical proposition and a reality which is definable only and exclusively in terms of measurability, i.e. a mathematisable reality?

I argue that even if randomness is located at the interface constituted by the computational bond of the measuring/cognising mind plus body, this should be considered part of the nature wherein measurement cannot but be applied. If this point is accepted, moreover, then what is there for the so-called interface to mediate? Between what, that is, does it intervene, and from where?

6.5: Final Remarks on the Definitional Spectrum of Noise

In the "The 'Information Metaphor Falsehood' and the 'Glorification of Noise'" section, we acknowledged that there is no discrete informational value for any part of a biological system. For this reason, a taxonomical classification of the different types of noise or its potential interchangeability with stochasticity, randomness, variation, variability or uncertainty does not seem to be advisable.

I should now make a technical distinction (as per different fields of research and where they are actually useful) between the terms "variation", "variability", "randomness" and "uncertainty".

We can conceive variability and uncertainty as two different classes of variation, each involving different sources and kinds of randomness. Authors such as Van Belle (2008) understand *variability* as referring to natural variation, whereas *uncertainty* refers to the degree of accuracy with which a quantity is measured. According to Bravi and Longo (2015: 2) *randomness* "may be understood as unpredictability with respect to an intended theory" and measurement. For Longo it is a constructive or enabling constraint[189]; similar to Kauffman et al.'s (2008: 31) information, "constraints are information and information is

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[189] Such as the two sides of a coin (constraints) enabling the (complete?) description of (and thus to determine) the toss of a coin.

constraints” but randomness (as well as noise) differs insofar as it presents a limit to predictability. Longo tries to make this limit precise in biology as “a component of production of an unpredictable” and “constructive production of diversity”. The overall problem of noise should be then reframed into an:

> … alternative epistemology of living beings which accounts for the structures of determination inherent to biology and for an autonomous definition of randomness sticking to this idea, history and contexts, as well as internal constraints of integration and regulation mechanisms, can be thought to constrain possible evolutionary paths that dynamically arise in the interaction with the environment rather than to determine the outcome (as determinism requires that the same effects derive from the same causes). (Bravi and Longo, 2015: 9)

According to Longo et al., as soon as we perceive what commonly is understood as noise taking a constructive role that leads the system towards robustness, they advocate for moving it into the category of functional randomness. The distinction between noise and randomness in its constructive role is thus of paramount importance. In agreement with Wilkins, Longo and his collaborators, I contend that they are not interchangeable. Rather, I argue that randomness is noise when it is interfering with a system, but as soon as it is integrated by the system as a stabilising element it becomes problematic to use the concept of noise, precisely because it is no longer perturbing the system. Thus, the distinction between the two is in reference to their functional roles. For Bravi and Longo (2015: 17) randomness in physics is “non deterministic or deterministic non-predictability within a pre-given phase space” while in biology randomness is intrinsic indetermination given by *changing* a phase space – ontogenesis and phylogenesis.

Chapter 7: Seize the Means of Complexity: A Critique of Pancomputationalism

> [C]omplexity, by its very nature is an impossible term to define … complex systems defy definition.
>
> Batty et al. (2014: 364)

> Thinking “operationally” has become a sort of absolute artificialism, such as we see in the ideology of cybernetics, where human creations are derived from a natural information process, itself conceived on the model of human machines. If this kind of thinking were to extend its dominion over humanity and history; and if, ignoring what we know of them through contact and our own situations, it were to set out to construct them on the basis of a few abstract indices [...]—then, since the human being truly becomes the manipulandum he thinks he is, we enter into a cultural regimen in which there is neither truth nor falsehood concerning humanity and history, into a sleep, or nightmare from which there is no awakening.
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> Merleau-Ponty (1964: 160)

7.1: Introduction to the Chapter

Some scholars argue that natural processes are deterministic and digital: all information must have finite and discrete means of representation, and the evolution of any physical state is governed by local and deterministic rules (Fredkin, 2003). This is in accordance with classical mechanics (e.g. Zuse, 1969; Fredkin, 1990). As maintained by "pancomputationalism", all physical systems (e.g.: atoms, crystals, whirlpools or pencils) execute computations (Piccinini and Gualtiero, 2017). If we understand computation as information processing, we could extend the notion and talk about "paninformationalism". For others thinkers, it is conspicuously evident that it is not possible to conceive the world as the outcome of classical computation (Feynman, 1982; Deutsch, 1997; Lloyd, 2010) since that would neglect processes showing quantum behaviour. The central issue that remains to be considered, however, is to reveal which processes are the most fundamental.

Physicists like Wheeler (1989) or Wolfram (2002), maintain that quantum phenomena are an emergent property of computation and information. The foremost positions against pancomputationalism argue that no present scientific theory can provide an accurate description of natural phenomena such as mental activity (e.g. Penrose, 1990), but argue instead for a world where indeterministic randomness in fact takes place, strict computable determinism does not hold, and so that free will becomes viable (e.g. Scheidl et al., 2010). They do so, for instance, by rigorously accepting the Copenhagen interpretation[190] of quantum mechanics. A weaker species of pancomputationalism involves an algorithmic depiction of the world and of nature (Zenil, 2011; Chaitin, 2012) without the requirement that it be embodied in some actual, particular computational model.

Surrounded by unknown sequences (sequences that we really desire to better understand), the 'real' world appears very noisy to us, uncertain and analogue and we remain just as ignorant when it is presented in the ill-fitting guise of a monochrome world of symbols and rules from computational complexity theory. There is a contrast between a self-confirming theory that

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[190] See for instance: Cushing, J.T. (1994), *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony*. Chicago: University of Chicago Press.

determines its own truth criteria and a noisy, messy world. Implicit therefore is an answer to the question whether noise is a formal or an ontological problem.

The algorithms we have created, do not scale up to an accurate perception in the real world, where things have complex forms, a huge range of reflectances, taste, touch, smell and lighting situations that are very difficult to govern. The real world is high-dimensional[191] and it might not be the case that there is a low-dimensional model that can be fitted to it (Breiman, 2001). This would present problems to the *modal* status of "semantic reductions" (Carnap, 1929) or "micro-reductions" (Oppenheim and Putnam, 1958) where entire theories were ultimately supposed to be reducible to more basic theories.

The first models of natural languages (constructed symbols and syntax) came up against almost identical difficulties. They overlooked and neglected the complexities of semantics (Chomsky, 1986). Practical natural language applications had been achieved thanks to the way in which the complexity of deep learning language models 'moved closer' to the complexity of the 'real world'. This entailed the study of "random properties of languages that are complete under various kinds of reducibilities from the complexity-theoretic point of view" (Huynh, 1992: 306). Models of natural language with millions of parameters and trained with millions of tagged examples are now used daily in our laptops, smartphones etc. Additionally, since our society invests huge amounts of money in the generation of "real true randomness" –cryptography, virtual reality, gambling, etc. We cannot neglect the potentially productive role of randomness and noise in their interdependencies with complex systems.

The motivations of this chapter are:

First (as advanced in the previous chapter): to develop an alternative characterisation of *noise as an enabling constraint*. In order to do this, we must first recognise that: *complexity is complex*. This is exemplified by the 'propensity' for complexity to become a 'disordered'

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[191] A dimension is a direction of freedom of movement, or in which an object can extend. On a one-dimensional line, a second dimension intersects it at one point only; in the same way, a 3D object can only be seen as a 2D shape on a flat 2D surface. Or put another way, higher dimensions can be projected on fewer dimensions, like your shadow on the sidewalk or a wall. If a higher dimensional object were to move in a higher dimension, all or part of it would disappear from our view. High-dimensional spaces arise as a way of modelling datasets with many attributes. Higher dimensions are values which make real measurements (and) yield more accurate results. But the higher dimensions themselves play no physical part in the measurement. You can think of them as virtual placeholders so the lower dimensional equations do not break. See: Skillicorn, D.B. (2012) *Understanding High-Dimensional Spaces*. Berlin: Springer.

concept – particularly in the social sciences, where mathematical formalization is a challenge and metaphorical expression is omnipresent. Thus, we must first mitigate this sort of 'noise in noise'. In order to do this, we will begin with an introductory exposition of some of the most common characterizations of complexity sciences (7.2) in order to synthesise a navigational landscape of complexity that helps us from falling into the traps of *systematic reductionistic turns* (resulting from the presumed scientific aim of predictive control) of which we will conduct a critique.

Two main strategies are used by those[192] who would reduce the complexity of complexity:

The first strategy is simplification by means of semiosis (meaning- or sense-making), which is related to specific systems of meaning. It will be helpful to understand how the biosemiotic field (7.3), embraced the tools of complex systems dynamics (including non-equilibrium thermodynamics, hierarchy theory, nonlinear dynamics and processes of emergence). Given the generalised, i.e. multi-disciplinary call to include information theory, metaphors of codes and language in the study of the semiosphere (Gatlin, 1972; Brooks and Wiley 1986, 1988; Collier, 1986), we need to assess both the relationship between relevance, meaning and eruption of information (7.3.1) as well as the way in which algorithmic information content (also understood as algorithmic randomness), Kolmomogov complexity and effective complexity are part of a *reductive* strategy attempting to aid the measure of complexity (7.4**)**. Governing bodies of 'honorable' political and scientific institutions as well as supposedly trustworthy representatives of the public (generally arising from mass-media) reduce systematically the programme of complexity sciences to predictive modelling – and hence, project this simplistic depiction into society[193]. They remove from the equation the issues of emergence and effectively deny the lack of predictive control, and thus, also the accountability when public regulatory decisions and justifications are made (in the name of science) excluding and/or externalising *risk* and *unpredictability*. Noise remains insusceptible of reduction to discreteness.

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[192] Complexity either *really is* complex, in which case reduction is an error; or it only *seems* complex but is simple really, in which case complexity *evaporates*.

[193] See for instance: Research Group of the Office of the Privacy Commissioner of Canada. (2012) The Age of Predictive Analytics: From Patterns to Predictions. [online] Available from: https://www.priv.gc.ca/media/1753/pa_201208_e.pdf [Accessed 18 September 2020]; Symons, J., and Boschetti, F. (2012) How Computational Models Predict the Behavior of Complex Systems. *Foundations of Science*, 18, 4. pp. 809–821.

Since complexity implies a trade-off between order and disorder, we are required to explain some elementary examples of complex dynamical behaviours, such as: chaos (7.5.1) and the context sensitiveness in which nature 'employs' the former in the production of enabling constraints (7.5.2) and useful randomness (Crutchfield, 2011).

The second strategy is simplification by means of structural organization –understood in a broad sense. Certainly, faced with complexity, simplification is basic for any operating system or agent in order to be able to navigate the world.

This leads us to the second motivation for this chapter: to explore the limitations of the use of *computational metaphors* in the ever-increasing speed and complexity of our current world. Thus, to provide a *critique of pancomputationalism*. This is not just rejecting the arguably erroneous view under which cognition equals computation, but emphasizing the fact that "[w]hat we can learn from the machines is how our brain must differ from them" (Lord Adrian, quoted by Canguilhem, 1963: 16). This alerts us to the fact that a society that convinces itself of the truth of "[e]pistemology naturalized by info-computation" (Dodig-Crnkovic, 2007) (the very first metascientific ideological substratum of cybernetics) is one stepping into the complete subordination of knowledge to technocapitalist interests (Stiegler, 2019), together with a reductionist account of our Second Nature[194]. If therefore such views upgrade Quine's hypothesis (1969) for societies more computerized than he imagined possible, it requires an upgraded *critique* in response, a critique it is in part the function of this thesis to provide.

In order to perform this critique, an examination of the computational metaphors for complexity will be conducted (7.6). It will involve a brief exposition of the universal Turing machine as well as Chomsky's hierarchy, which classifies the class of languages that are accepted by the different machines. Hierarchy theory has been a crucial element of ecological theory for more than 20 years. It has also been extensively implemented in social and economic analyses. It is notably fruitful for questions of constraints, scaling problems and system controls. Systems theory research exhibits a problematic divorce between hierarchical

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[194] Understood in Marxist terms:

> Nature builds no machines, no locomotives, railways, electric telegraphs, self-acting mules etc. These are products of human industry; natural material transformed into organs of the human will over nature, or of human participation in nature. They are organs of the human brain, created by the human hand; the power of knowledge, objectified. (Marx, 1993: 706)

(top-down or bottom-up) and network (peer-to-peer) analyses. The concept of heterarchical organisation (7.6.2) combines these perspectives in a single framework at the same time as addressing the inadequacy of the former for developing a brain-computer analogy. This will help us to illustrate the operational function and the limitations of computational metaphors across the world order (7.7). How this species of "cyber-Umwelt" reconstitutes human nature as a decentralized quantity of networking patterns of information, algorithmic communication, and feedback loops. This chapter ultimately presents the problems behind the way in which these organicist techniques (digital techniques for the organisation, management, governance of life[195]), geared together, institute patterned "mechanisms working to generate, incite, reinforce, control, optimize and organize the forces [… that are] now situated and exercised at the level of life" (Rabinow and Rose, 2006: 196).

7.2: Myriad Complexities

We face a significant lack of an accurate characterization of complexity. Complex systems have been declared to be open, far-from-equilibrium (Nicolis and Prigogine, 1977), non-linear (Nicolis and Nicolis, 2007), adaptive (Holland, 1996), on the edge of chaos (Kauffman, Langton, 1990), non-algorithmic (Rosen, 2000; Wegner, 1997), or to have been synthesized bottom-up (Holland, 1998) –to name only a few of many other attributes or features.

The so-called sciences of complexity are comprised by various different sciences (i.e.: complex networks: Strogratz and Watts, 1998; non-equilibrium thermodynamics: Prigogine, 1961; chaos: Lorenz, 1963), several theories (self-organization: Camazine et al., 2002; catastrophe theory: Thom, 1976; turbulence: Wolfram, 2002), approaches (first and second phase transition order: Solé et al., 1996; swarm intelligence: Garnier, Gautrais and Theraulaz, 2007), methods (simulation and modelling: Axelrod, 1997; North and Macal, 2007; metaheuristics Talbi, 2009), concepts (failure cascades and percolation: Bak, Tang and Wiesenfeld, 1987; learning and adaptation: Holland, 1996) and problems (randomization: Kolmogorov and Uspenskii, 1987; optimization: Dorigo, 2005; crises: Taleb, 2010) –again, just to offer some examples. The political implications of the complexity sciences have also

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[195] What Foucault might have called "digital biopower".

been stressed[196]. They explore some of the most basic political implementations of these sciences based on historical, legal and/or social scientific approaches[197] –often, what we find are methodologies oriented towards policy development. These frequently fall short when critically addressing the ever-growing rate of technological acceleration that impregnates and transforms the most fundamental spheres of our life. Here I would like to offer a set of *realist cues* of critical character, precisely in order to be able to politically interpret the impact of those sciences.

We do not possess a sort of 'first-rate' approximation for addressing complex systems in a univocal way (their processes or phenomena). In the same way, there is no domination of one particular method (of the aforementioned) over the others. One of the most significant milestones for complexity theory has been presenting the evidence and demonstrating that there is no such a thing as a closed system (Tsuda, 2001). This is a fact precisely because the environment's influence on a system is always to some extent *uncontrolled*. Ideologically, denying that there is an outside is a *precondition* of asserting isolated or closed systems. Critically, therefore, we may characterize such systems as either hypostatizations of theoretical and/or experimental constraints. As we have seen, there is an obvious counterpoint: there is no single field, method, language, approach or even science that with its definition or characterisation, embraces the whole manifold of the complexity sciences. This point, too, is a matter that may be normative (should there be such characterizations?), modal (can/must there be?) or ontological (*if* there are no single characterizations of complexity and complexity obtains, what is Being?) These questions are essential to the critique of pancomputationalism.

So there is no clear and decisive solution to the problem: what do we understand by a complex system? A proper interpretation of the ever-increasing complexity of systems is quite resistant to classical methods that are reductionist and deterministic. It is commonly known[198] that for instance, linearization, isolation and parameterization of processes and systems, turns out to be not only unproductive but unnecessary and 'artificial'. On the other

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[196] Alberts and Czerwinski, 1997; Jervis, 1998; Richards, 2000; Sanders and McCabe, 2003; Heartney, 2004; Boin et al., 2005; Wynne, 2005; Harrison, 2006; Geyer and Rihani, 2010; Boulton, 2011; Maldonado, 2013; etc.

[197] An exceptional exception is the most recent: *Political Hegemony and Social Complexity: Mechanisms of Power After Gramsci* by Alex Williams (2020). London, Berlin: Springer. First book to integrate complexity theory with the theorisation and practice of hegemony.

[198] See: Maldonado, C. and Mezza-Garcia N. (2016) Anarchy and complexity. *Emergence: Complexity and Organization*. 2016 Mar 31 [last modified: 2016 Oct 12]. Edition 1. doi: 10.emerg/10.17357.fb8bba71f0ea3b9e2159ee2b741a1efe.

hand, a remarkable characteristic of complexity is in fact: the way in which it exhibits alterity and diversity; plurality and multiplicity. If complexity sciences have been regarded as interdisciplinary or cross-disciplinary, they are then described by a myriad of concepts, approaches and theories.

It is safe to say that complexity sciences *demand* a philosophy of change. Chaos theory, catastrophe theory (Thom, 1972), plectics (Gell-Mann, 1995b), dynamical systems theory (Abraham, 1994), and complexity theory are all interested in the study of dynamic systems. Murray Gell-Mann[199] tried to introduce the notion of "Plectics" (from Greek πλεκτός (*plektos*): "braided") in the early 90s for the field of study described in his own words as: "a broad transdisciplinary subject covering aspects of simplicity and complexity as well as the properties of complex adaptive systems, including composite complex adaptive systems consisting of many adaptive agents" (1995: 3).

In contrast with the science of the modern period, complexity science does not concentrate on uniform, cyclic, regular movements. Such movements are, in fact, the object of study of classical mechanics, which determines and provides explanations for regular phenomena in terms of law-like theories. In effect, the notion employed from Galileo to Newton to manifest such type of movement was *revolution* – from late Latin *revolutio*(*n*-), from Latin *revolvere*[200]. On the contrary, complexity theory concentrates on unpredictable, irregular, sudden, aperiodic and irreversible movements. It is precisely this kind of movement that is interpreted by the notions and methods mentioned earlier. Modern science is the science of normal distributions, prediction and control, the primacy of determinism, causality and reductionism (Casti, 1991; 1994). Conversely, complexity science focuses on emergence, power laws and order through fluctuations etc.

I would like to argue here in favour of an understanding of complex phenomena in terms of increasing numbers of degrees of freedom. The notion of degrees of freedom is crucial to help us with the interpretation of complex processes. A system that acquires degrees of freedom is understood as being of increasing complexity, and nonlinearity is useful here as an appropriate notion for us, since we are compelled to work with the *n* options that the system

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[199] Gell-Mann was one of the co-founders of the Santa Fe Institute In 1984 — a research institute in New Mexico. Its purpose is to study complex systems and advance the cause of interdisciplinary studies of complexity theory.

[200] See: e.g., chapter X of Kuhn's (1962) *Structure of Scientific Revolutions*. Chicago: University of Chicago Press, as well as Alexandre Koyré's work, especially *Études galiléennes* (1939) Paris: Hermann.

offers us in a concurrent way, that is to say: without the possibility of choosing or maximizing a specific option from the ones accessible by the system.

I would like to present an understanding of complexity theory that is not merely about explaining and interpreting self-organized, emergent and non-linear systems and processes, but equally importantly seeks to complexify processes, systems and phenomena. We feel compelled to re-emphasize this particular issue: complexity theory should consist in both: a) to offer an explanation and to comprehend the processes whose activity requires the acquisition of degrees of freedom, and b) the ambition to improve and partake in the creation of an increasingly complex world(s). In light of this, the notions consonant with “degrees of freedom” are: randomness[201] and “bifurcation”.

A bifurcation is the abrupt change of a given phenomenon departing from what was early described as a metastable state. Closed systems reach “stable equilibrium” and stay there. Open systems reach metastable states from which they can be moved (bifurcated) by external perturbation, so that either a system increases in complexity or undergoes what can also be understood as a qualitative change of a system. For the most part, bifurcations occur through a first or second order phase transition (Solé et al., 1996; cf. chapter 3). Consequently, bifurcations run in parallel with non-linear phenomena and, as a result, the system under study obtains new degrees of freedom as a function of increasing complexity. “Each bifurcation results in a more complex spatial and/or temporal pattern” (Reiss, 1983: 57). Such a phenomenon can be explicitly understood as the operation by means of which the system unleashes itself from stillness and control.

That is to say: as complex systems gain degrees of freedom through bifurcations, they are moved towards the edge of chaos where it becomes more difficult to control them. It has been maintained (Kauffman, 1995; Gould, 2000; Sole and Goodwin, 2008) that evolution entails edge of chaos bifurcatory behaviour in systems (from the molecule to the ecosystem), rather than their being driven by any teleological governor, i.e. by any optimality or finality of outcome. The dynamics, structure and organization are a product of self-organised interdependencies that do not follow any teleological path. We could therefore say that complexity theory analyses the behaviour of systems of ‘anarchic nature’ –systems without a ‘governing body’. Accordingly, complexity science should seek complexification rather than

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[201] As we have seen in previous chapters, Kolmogorov and Chaitin characterise a complex system as (in last instance) a random one.

simplification (see the discussion of the two principal strategies of simplification above) precisely because only such a science is adequate not merely to the products but also to the behaviours of a nature that is precisely anarchic. Complexity science should not aim to produce static and fixed models of a nature, whose laws might have changed over vast spans of cosmic time[202], or could be understood as a kind of accumulation of the constraining influence of the "given" (Whitehead, 1978). The world demands *progressive* rationalisation (Wilkins, 2021) and constant Bayesian revision of our prior givens.

7.3: Eruption of Information in the Semiosphere: Eigentümlichkeit and Constraints

To say that something is complex, is to make a statement about a clearly context-dependent fact. That is: complexity depends not only on the thing being described, but also on who or what is doing the description process. Ask yourself this question: is it not the case that "one man's signal is another man's noise"? Because, although the idea of complexity may be hard to define with exactitude, it is nonetheless evident that it is closely related to (in fact, intertwined with) the notions of information and neg-information, and hence *noise*.

What we are getting at here is an internally self-complexifying sender-receiver relation made more complex by being one of many in the informational landscape –i.e. semiosphere. Noise is then not just an ontological precondition for any ordered process of individuation to emerge, but it is always generated with every intervention in any semiosphere. Hence not just "noise" (abstract quantity) but *noxiogenesis*. The semiosphere is the informational landscape redrawn with every attempt to extract surplus meaning. Schelling's treatise on the place of biology in the natural sciences, *On the World Soul*, anticipates von Uexküll's identification of species-specific semiospheres in an argument of what Schelling named the "sphere of characteristic impressions" (*Sphäre eigenthümlicher Eindrücke*) (*W*: 248) –through which all organisms 'decipher' the world and find their paths within it. This sphere of characteristic

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[202] See: Wilczynska, M. R., Webb, J. K., Bainbridge, M., Barrow, J., Bosman, S. E., Carswell, R. F., Dąbrowski, M. P., et al. (2020) Four direct measurements of the fine-structure constant 13 billion years ago. *Science advances*, 6 (17), essay 9672. [online] Available from: https://www.repository.cam.ac.uk/bitstream/handle/1810/305010/eaay9672.full.pdf?sequence=3&isAllowed=y [Accessed 2 October 2020]

impressions is problematic insofar as it presupposes the romantic concept of what is particular to oneself, “*eigentümlichkeit*”, i.e., of ‘proprietariness’, as its bedrock. Schelling’s idea [111] might not have permeated his contemporaries and immediate successors, but the transversal influence of von Uexküll and C.S. Peirce on biosemioticicians such as Kalevi Kull and Jesper Hoffmeyer helped them in the reconsideration of this idea. Barbieri, (2008); Favereau, (2010); Emmeche and Kull, (2011); Schilhab, Stjernfelt and Deacon, (2012) are achieving great and rapid advances in their studies of this idea. For these scientists, life results from the operation of signs, and humans are the symbolic species[203]. Building on these notions, they have continued with the interdisciplinary method of figures like Bateson. Bateson’s cybernetic re-elaboration of information as “a difference which makes a difference” (1972: 459), together with von Foerster’s second-order cybernetics, paved the ground for Søren Brier’s work on the unification of a non-mechanistic conceptual schema for cyber-semiotics, building of bridges between human and natural sciences (2010). This research has been expanded by the rediscovery of Howard Pattee and Robert Rosen, by scholars like Timothy Allen, Stanley Salthe and Alicia Juarrero, all exploring what Schelling understood by emergence comprising the establishment of new productive “limit-points”[204] on activity –or in Pattee and Rosen’s[205] words: *constraints*. Patte was in fact interested in clarifying the emergence of hierarchical orders of symbols and control. He expanded on Michael Polanyi’s notion of hierarchy based on the reflection that deterministic laws both assume and function within the limited conditions generated by lower level orders (Polanyi 1958, 1969).

One of the main issues with the conception of “emergence out of constraints” is the presupposition under which fractionated elements exist autonomously and are to some extent constrained to form part of the new emergent system. This is related to the inclination to perceive the emergent system as supervening over lower level systems, neglecting the environment in which these systems were able to function in the first instance, and subsequently the new additional environment generated by the emergent system. Salthe

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[203] See: Langer, S. (1942) *Philosophy in a New Key: A Study in the Symbolism of Reason, Rite and Art*. Cambridge, Mass: Harvard University Press and Cassirer, E. (1923-1929) *Philosophie der symbolischen Formen*. Bruno Cassirer: Berlin.

[204] “limit-points do not mark the failure of construction, but the emergence of a new product – the concept – that is a recapitulation of the asymmetrical identity of productivity and product” (Grant, 2006: 169)

[205] It has been argued that Rosen’s very conception of emergence has its roots in Schelling’s philosophy of nature. See: Gare, A. (2002) Process Philosophy and the Emergent Theory of Mind: Whitehead, Lloyd Morgan and Schelling. *Concrescence: The Australasian Journal of Process Thought,* 3. pp. 1-12.

(1993) adjusted this perspective indicating that emergence (in both development and evolution) is connected with *interpolation* among processes of smaller and larger scales, as well as faster and slower velocity rates. A constant interpolation, that seems to *us*, essential to prevent the "eigentümlichkeit discretisation" (translatable as, the discretisation of singularity, individuality, distinction), and helps altering both the longer and the shorter scale processes. Allowing a position to climb hierarchies that was then employed in the description and explanation of final causes. As Salthe pointed out: "constraints from the higher level not only help to select the lower level-trajectory but also *pull it into its future* at the same time. Top-down causality is a form of final causality" (1993: 270, emphasis added). As Alicia Juarrero states: "[c]onstraints thus turn the amorphous potential into the definite actual […], constraints effect change. And in-form. Constraints embodied in encryption rules also take the signals away from equiprobability and randomness." (1999: 134). We will explore the enabling capacities of constraints in 7.5.2, but first we need to address the role of relevance and meaning in the decryption of any informational landscape. The next section at its core is an exploration of the semiosphere, and looks at how this concept helps us to problematize the basic assumptions of pan-computationalism.

7.3.1: Eruption of Information in the Semiosphere: Relevance and Meaning

The very same signal may be significant and senseless in one context, or sensical but insignificant in another. In other words: meaning must be specified relative to some context: an extensive spatio-temporal range of information, the agent's internal and external structure, etc. Additionally, *context-specification* is not informationally *cost-neutral*[206] or, in other words: is itself *noxiogenetic*. A whole *context* that is much *bigger than* the *signal* whose data is to be decoded. There is no "ontological reducer" capable of fitting the bigger into the smaller[207]. The context sets out the information relative to which the meaning of any signal is decoded. The example of a white noise[208] signal helps us to understand that it may entail zero meaning for us, although it exhibits a high bit rate information-richness in signal processing.

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[206] Specifying a context requires (costs) information processing, this process entails extracting the context from the background noise, so to speak.

[207] As an example, let us say that the context in which rock music provides meaning is much bigger than the signal (we can think about an audio tune of a band registered in a physical medium) whose data is to be decoded. Then, the specification of this context, this milieu, umwelt, etc. there is no way in which we can compress it, we have no ontological tools of reduction to fit the bigger into the smaller, to understand the context just within the boundaries of the discrete registered piece of information.

[208] A random signal that presents equal intensity at different frequencies, endowing a constant power spectral density.

This sheds light on the counterintuitive character of Shannon's information: a signal can have low meaning and high information, or low levels of information (e.g.: musical tunes or a conversation, examples which are highly redundant in the informational sense) and high meaning.

Is it not possible to have a communication that only involves encoding, transfer, and decoding of messages. "Every act of ostensive communication communicates a presumption of its own optimal relevance" (Sperber and Wilson, 1986: 260). Relevance depends not only on present external conditions, but also on the observer's present cognitive state: objectives, motivations, internal questions or the thesis being assessed. It is not just the "internal/external" relation that matters to this account, but rather that the internality in which cognitive states spring is precisely also the externality giving rise to both, this contributes to understand how cognitive states are necessarily restricted with respect to their input. Therefore, relevance we could say is in "the eye of the beholder", and requires a formalization of the external conditions *and* the goal-directedness of the observer's present cognitive state. Indeed, arguably, "relevance" is always entirely organic (nothing is "relevant" for the Sun or a lepton), and is the entire basis for the birth of normativity in the world. This characterisation provides us a positive account of teleology; it offers the inseparably normative element in focus adjustment (relevance); and it clearly entails a strong disanalogy between evolutionary conceptual frameworks and "semiospheric" ones.

Theoretically, anyone using pancomputationalist assumptions should be capable of characterising the ideal observer's ("ideal interpreter") models that can obtain and abstract all the potential relations between all possible signals for a given world and trajectory towards a goal. They imply that the world can only compute and take the shortest route to heat death, the detour of evolution as a local solution to expenditure just happens to be that shortest route. The resultant (and expected) combinatory eruption of possible combinations, presents important challenges to the employment of such models in the government of actions. This is because a set of computations put through an unbounded combinatory eruption of possible combinations does not make much sense in any real-time computation of meaning. This is known in artificial intelligence as the notorious "frame problem" (Ford and Pylyshyn, 1996), and the solutions within AI have so far, all basically set a priori constraints for the dimension of this eruption. All are versions (to some extent) of Chomsky's innate biases or in Simon's terms "bounded rationality" (Simon, 1957). On the other hand, it is not clear that such constrained models are up to the apparent ‘unchained’ discovery of connections that human creativity with language has shown, as well as its direct role in the production of culture, arts and science. No perfect observer model can obtain *alone* the relevance of a signal without the complementary set of context(s). If the eigenthumlichkeit (supposedly necessary for a “discrete, perfect observer model”) ‘collapses’ we are compelled to discuss the informational landscape that echoes this collapse. The semiosphere[209] continuously assigns constraints or boundary conditions on the “umwelt”[210]. We are referring to a semiotic continuum addressing several diverse transformations, situated at various scales of organisation. The semiosphere remains delimited by the space that circumscribes it, which is exterior to it or pertaining to different semiotic spheres. Following Lotman (2005), the semiosphere requires a sort of coherence or continuity so that it is possible to discern something from the point or bifurcation where (or when) it ceases to be what in consequence becomes what it is not and, reciprocally, is not it. The processes of transformation take place on its boundaries as *translations*. Such translational processes enable a transformation operation that involves the catastrophic nature in its lack of continuous stability and structural asymmetry[211] between the exterior and the interior (centres) of the semiosphere. Moreover, Lotman (2009) makes a distinction between explosive and gradual processes. This notion of ‘explosion’ is precisely what operates as the driving force behind the pursuit of meaning by living things. Perturbing, interfering with a relationship in continuum, the explosion turns the future uncertain. This activates a process of signification, insofar as ‘‘[t]he uncertainty of the future allows significance to be assigned to everything’’ (Lotman, 2009: xxiv). The instant of explosion is a sudden rise of meaningful information from the entire system –explosion instead of either “point" or “bifurcation”; punctual rather than gradualist noxiogenesis. The time needed to reach the exhaustion of the explosion is an ‘inflection’ point in the process (ibid.). The disparity of velocities of change (between the stable and slow interior centre and the rapid

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[209] Coined by Yuri Lotman in 1984. Semiosphere is the sphere of semiosis in which sign processes operate in the set of all interconnected Umwelten. See: Lotman, Y.M. (1990) *Universe of the Mind: A Semiotic Theory of Culture*. Bloomington, Indiana: Indiana University Press, and Lotman, Y. M. (1984) O semiosfere. *Sign Systems Studies* (*Trudy po znakovym sistemam*), 17. pp. 5–23.

[210] The notion of Umwelt was introduced by Jakob von Uexküll in (1909) *Umwelt and Innenwelt de Tiere*, 2. verm. u. verb Aufl. Berlin: J. Springer, and (1928) *Theoretische Biologie*, 2. gänzl. neu bearb. Aufl. Berlin: J. Springer. It can be understood as a species-specific “subjective world of an organism” (Emmeche, Kull and Stjernfelt 2002: 30). The Umwelt of a species of object-system is the environment (or even more broadly the world) as it is presented for the object-systems in accordance with their species specific (sensory) capacities. The notion of environment is understood in this context as a meta-level concept, the environment of an object-system is determined (or specified) from the outside by the meta-agent, the observer, scientist etc. See: Emmeche, C., Kull, K. and Stjernfelt, F. (2002) *Reading Hoffmeyer, Rethinking Biology*. Tartu: Tartu University Press.

[211] As we see in Thom (1972).

and turbulent exterior) results in further changes and in consequence, rendering any system prone to such disparities “multi-centred” –because: in noxiogenesis, no system has a discrete quantity of attractors. Lotman maintains (ibid.) that in any semiosphere, there is a dynamic tension between uniformization and differentiation, characterizing this frictional process as a structural paradox. This dynamic tension does not obstruct the progress of a semiotic system; quite the opposite, it is the driving force of its development. We can see the process of uniformation ensuring the continuity and integration between the different elements, at the same time that differentiation makes possible the expansion towards new functions, capacities and elements. Thus, we can contemplate these processes of catastrophic transformation corresponding to both: spatial dimensions between the interior (centre) and the exterior, and to the temporal aspect of the various transformation velocities.

In the next section, complexity is going to be addressed from the point of view of measurement in information theory and in section 7.5 from the point of view of dynamical behaviour.

7.4: Measures of Complexity: Noise’s Irreducibility to Discreteness

Every account of complexity as a state necessarily fails not because it is a false description of a real state, but because complexity is often misconceived as a state rather than the process it is. The objective of this section is to make clear that noise is insusceptible of reduction to discreteness. In other words: no adequate analysis of complexity can be supplied by reducing it to an isolable, discrete, and therefore simple state, because its indiscrete, processual nature undermines this simplicity.

There are many competing formal accounts of complexity, though not all have equivalent ontic purchase. To illustrate this, I will contrast here “Algorithmic Information Content”, “Kolmogorov Complexity” and “effective complexity”. From this contrast the salient features of what complexity is and is not (for information theory and computer science) will emerge, their limitations will be made explicit, and the critique of Shannon formalism in these domains will be continued.

During the 1950s and 1960s, various ineffective approaches were conducted in order to measure the complexity theories, particularly when formulated in the context of first-order logic. A remarkable example of these was Karl Popper's idea of identifying the degree of simplicity with a degree of falsifiability (or strength) (1959b: 140). In contrast, Nelson Goodman (1972), proposed an illustration of the problem, that shows how simplicity can neither be equated with strength (as Popper hopes) nor with safety:

> 1. All maples, except perhaps those in Eagleville, are deciduous.
> 2. All maples are deciduous.
> 3. All maples whatsoever, and all sassafras trees in Eagleville, are deciduous.
>
> (1972: 335)

Evidently, the second of these propositions is the simplest, and is more appropriate than the others if coherent with the data. On the other hand, 3 is stronger than 2, while 1 is safer (has the stronger possibility to be true) than 2. According to this, neither the strongest nor the safest proposition would be necessarily the simplest. Kolmogorov complexity provides a quantitative measure for complexity and simplicity. In other words: a string X (a model, a theory, etc.) is simple insofar as its Kolmogorov complexity is low. It is not a surprise then to perceive how *simplicity* comes up as a *progressive attribute*: things are not simple by definition, but they may progressively become more or less simple.

Kolmogorov complexity can be employed in the formalization of the property of randomness of finite or infinite binary strings relative to some probability distribution and it is specified in relation to a "Universal Turing Machine"[212].

In the decade of the 1960s, Kolmogorov, Chaitin and Solomonoff (all working independently) came up with the notion of "Algorithmic Information Content"[213](AIC), which measures the length of the shortest program of a standard universal computer that prints a binary string in which the description of an entity is being coded (in a given language) at a given level of detail. Murray Gell-Mann provides us here an interesting insight regarding this notion:

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[212] A basic explanation of a UTM is provided in 7.6.

[213] See: Zurek, W.H. (1991) Algorithmic Information Content, Church-Turing Thesis, physical entropy, and Maxwell's demon, in *Complexity, Entropy and the Physics of Information*. Addison-Wesley. pp. 73–89.

> A string consisting of the first two million bits of pi has a low AIC because it is highly compressible: the shortest program just has to give a prescription for calculating pi and ask that the string be cut off after two million entries. But many long strings of bits are incompressible. For those strings, the shortest program is one that lists the whole string and tells the machine to print it out and then halt. Thus, for a given length of string, an incompressible one has the largest possible AIC. Such a string is called a "random" one, and accordingly the quantity AIC is sometimes called algorithmic randomness. (1997: 3)

Coinciding with Wilkins' (2021) reading of Crutchfield (1994), algorithmic compressibility does not constitute an appropriate measure of a structure (or pattern) given the fact that it presupposes the stipulation of a language, while in fact, encoding and compressibility vary across different languages. Once again: complexity is a multi-faceted word. It is easy to realise that when we talk about complexity in our daily lives, the notion we are dealing with differs substantially from what the AIC measures. There are different examples that can help us to understand this. For instance, we can think about the painting *Las Meninas* by Diego Velázquez (1656) or a painting of the same size and quantity of oil paint quasi-equally distributed over the canvas by a dripping machine –a mechanically-automated Jackson Pollock. It is ridiculous to think that such a machine has produced something more complex than the work of Velázquez. Randomness is not what we understand by complexity in our every-day use of the notion. The AIC of *Las Meninas* and the mock Pollock might be similar, but the complexity we attribute to them is extremely different.

Because of AIC's patent inefficacy in aiding a human's comprehension of complexity, Gell-Mann and Lloyd proposed what they regards as "effective complexity" as a metric associated with AIC but which is really an alternative to it, since it is more harmonious with our common ideas about complexity (Gell-Mann, 1995; Gell-Mann and Lloyd, 1996). Effective complexity presupposes that any given object is constituted by means of both regularity and randomness. This opinion has been explicitly endorsed by several authors, for instance: "[t]he most complex entities are not the most ordered or random ones but somewhere in between. Simple Shannon entropy doesn't capture our intuitive concept of complexity." (Mitchell, 2009: 98) Shannon entropy 'just' accounts for the uncertainty of a random process, it does not suffice in order to capture –not just our *intuitive understanding* (folk epistemology), but also something *real* (ontology) about complexity– what it *is*. Lloyd and Pagels try to improve this conception of complexity specifying that:

> [d]ynamical systems range in a continuum from completely ordered, regular systems like the arrangement of carbon atoms in a diamond crystal to completely disordered, chaotic systems like molecules in a gas. The intuitive notion of complexity ... is that complex systems lie somewhere in the continuum between order and chaos. Polymers, cells, brains and chickens are all structurally complex – they are neither wholly ordered or wholly disordered. Any reasonable measure of complexity should therefore vanish for the extremes of complete order or disorder and not vanish for the structurally intricate systems between these extremes (1988: 187)

For Gell-Mann, randomness (by definition) 'lacks interest' in terms of formalism, so he can employ the AIC formalism (an extension of Shannon's formalism) to the non-random elements of the system: "[t]he amount of information needed to describe the set of identified regularities of an entity is that entity's *effective complexity*. An information or entropy term describing the random component can be added to the effective complexity to yield what we call the *total information*" (Gell-Mann and Lloyd, 1996: 45). "Total information" is also addressed in terms of "augmented entropy", highlighting the connection between the two. "Effective complexity measures knowledge, in the sense that it quantifies the extent to which an entity is taken to be regular, non-random and hence; predictable. The remaining features of the entity are taken to be irregular and probabilistic." (ibid.: 49). Science as public knowledge seems committed to suppress any open reference to unpredictability and unknowns –only instead to (controllable and known) risks and uncertainties (Wynne, 2001).

Still, Kolmogorov complexity, AIC and effective complexity propose monolithic metrics in all contexts. There is a model dependency, there is no (computable) all-purpose measure of randomness or complexity, and it is unlikely that there will ever be a 100% objective measure of complexity. A statement about complexity will always be, to some extent, a statement about both the observer and the observed, with all the never-ending changes that this entails.

7.5: Complex Dynamical Behaviour

This section has as its purpose the present proposal, namely, that noise entails not just the disruptive actuality but also the systems-poietics to which it gives rise. It is because noise is both processes (crisis (disruption) *and* poiesis (production)) that I propose to talk not in the antagonistic terms of noise and system, but rather of the noxiogenesis that exploits every system's inability to master all its possibilities, and educes new possibilities within systems that take them beyond themselves.

7.5.1: Processes Exhibiting Chaotic Behaviours

As Gleick argued, the research into "chaos is a science of process rather than state, of becoming rather than being" (1987: 5). We have seen in chapter 4 how humans are extraordinarily talented at finding patterns embedded in noise. This sensitivity to structure and uniformities is the basis of plenty of the inductive leaps representative of our cognition as a species. For instance, the capacity to recognise speech in the midst of the street background sounds, or identifying the existence of a common cause constituting a set of circumstances. These examples of induction performed in our daily lives diverge significantly from the types of inferences ordinarily studied in statistics and machine learning: human cognition generally consists in achieving robust conclusions on account of a restricted amount of data, while many statistical analyses concentrate on the calculus of approximations of large samples.

Complexity entails a tension between order and disorder –often it emerges precisely at the productive edge of these two states, their friction, so to speak. Natural systems, in the course of their evolution, will be led by, and 'learn' from the interplay with their contiguous surroundings, displaying both structural order and dynamical chaos. The probabilistic distribution of the transformation of appearances from one thing to another (in which we have seen that noise takes an active role), necessitates distinguishing *noisy* from *chaotic* behaviours. From our unavoidably limited epistemic perspective, it is very difficult to know if the data of an observed process exhibits a random or chaotic behaviour –since in practice no time series consists of a pure signal. There will always be some form of *corrupting* noise, even if it is present as a round-off or truncation error. Thus, any real time series, even if mostly deterministic, will contain some (pseudo-)randomness (Brock, 1986). When we classify dynamical systems as chaotic, we are talking about *deterministic* systems whose behaviour can *in principle* be predicted, but *after a while,* these systems appear to be random. Small-scale perturbations to the system get exponentially amplified. Edward Lorenz famously characterised it (1963) as what we now call "the butterfly effect".

I would like to emphasise that in the dynamics of noise, or in the noise-induced/noise-oriented dynamics of a system, the potentiality that we can obtain, consists in the possibility of the emergence of new order or new information. This entails a dialectical process of exchange that moves noise away from a unilateral characterisation based on determinism or indeterminism –although the examples we have seen tend to be reduced in deterministic (chaotic systems) or indeterministic (stochastic process) terms. Deterministic chaos appears without any random force in the equations. We cannot explain complexity in terms of either deterministic chaos nor randomness, but as a phenomenon that is different from both. Deterministic dynamics producing chaotic patterns are estimated with the help of regular patterns (easy to predict over very short time-frames), conversely, randomness is never predictable –even at the shortest time-frames. This also applies to complexity produced by a deterministic dynamical system: across short enough time-frames, every single deterministic system, including both chaotic and complex[214], are ordinarily predictable. Stochastic (noise) processes, on the contrary, are not able to be predicted precisely even across the shortest time-frames. We have to take into account the delicate balance between this chaos and the influence or orienting capacity of noise within and beyond a system. Noise-induced variations cannot appear in a closed (theorised) equilibrium system (Gitterman, 2008), noise may be due to random variations in the associated milieu. The distinction between noise and chaos resides in the processes and the simplicity: chaos is produced by simple, controllable processes, noise by a large number of uncontrollable processes. But the boundary between the two is not well defined: there is a continuous transition from chaos to noise, when increasing system complexity (Tsuda, 2001) beyond given systems, producing as yet unactualized potentials. We may, in addition, see this shift from noise as a negative to a positive valency by addressing such phenomena as not only noxiogenetic but as noxiopoietic[215]. The question is, how these noxiopoietic potentials can be harnessed.

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[214] While it might be easy to understand Chaos as a highly complex type of complex system, It is not. Chaos theory has provided some remarkable insights, like sensitivity to initial conditions, but Chaos Theory is still a *study of deterministic systems*. In order to comprehend non-deterministic systems (like the human brain) it is necessary to look at complex systems with many constituent parts whose interaction outcome can be inherently unpredictable.

[215] The term does not signify simply the “production (poiesis)” of noise, but noise as productive; the noxia, in other words, is itself poietic, rather than the poiesis ‘noxic’.

7.5.2: Context Sensitive Enabling Constraints: Noxiopoiesis

We have to consider (as highlighted by Salthe, 1993; Juarrero, 1999; Felin, et al, 2014 and Wilkins, 2021) the “enabling role” constraints play.

We know order is at the basis of communication between elements across all stages of an organization, whether that is in reference to humans taking part in a subculture or the millions of axons travelling through our spinal cords. For an agent, order is the extraction of uniformities abstracted from its observational feedback. As testified more than a century ago by D’Arcy Thompson’s *On Growth and Form*[216] (or in the present time by Evo-Devo theory[217]), the very morphological evolution of an organism (its *shape* or *shaping*) responds to structural and functional principles inherited from its ancestors’ evolutionary (as well as its own) developmental ‘records’. Such records establish the repeated formative behaviours of that organism and therefore constrain subsequent development. Hence Alicia Juarrero's claim that..."[c]ontext-sensitive constraints, […] are a mechanism for morpho-genesis” (Juarrero, 1999: 140).

But on the other hand, a *fully* ‘ordered’ world, would be null in ‘in-formational’ terms, it would be an undifferentiated whole in which there are no energetic differences that can be exploited to perform work or variation in particle distribution. If a fully ordered world is informationally null, then it lacks sufficient noise to enable differential accounts of it to be generated. A noisy world is therefore one whose nature entails that it generates multiple accounts of itself. We require chaos in order to have life. What we understand as complexity, is possible thanks to context-sensitive enabling constraints (ibid.) operating at that dichotomy. Ethological variation (noise), for instance, is crucial for a species in order to avoid extinction, though there are constraints: there is no animal, for instance, that can model its umwelt in its entirety.

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[216] Thompson posed that the form is the result of a diagram of forces. The form is the result of both the (physical) forces from which it was produced and those that maintained it in time. See: Thompson, D.W. (1917) *On Growth and Form*. Cambridge: Cambridge University Press.

[217] See: Minelli A. (2004). *Evo-Devo*. Rome: Nuova Argos.

Estimation turns out to be fundamental to any system with limited means. Chaos (as we are now able to 'depict' it) is the "dynamical mechanism by which nature develops constrained and useful randomness" (Crutchfield, 2011: 23). From it follow variability and the capacity to forecast the uncertain time to come. There is a propensity (whose principles science is just starting to understand in the last decades[218]) for natural systems to countervail both order and chaos, to drive towards the point of intersection between uncertainty and predictability (ibid.). As a consequence, it produces a higher structural complexity. It is really shocking to see how: "increasingly complex order and structure characterize both cosmological and biological evolution" and there is no apparent compliance with the 2nd law of thermodynamics (at least at the local level) leading to a "relentless disintegration and disorder. The behavioral repertoire of a more complex species is larger than that of the species from which it evolved" (Juarrero, 1999: 136). This frequently emerges as a transformation in a system's internal computational competence. The current situation of evolutionary transformations suggests that we are required to take it one step further and speculate about the force (or forces) that drives time in the direction of a progressively more complex and qualitatively more diverse internal computation. This, undoubtedly entails one of the most remarkable riddles: how is it possible that disorganised elements of a system in nature, are capable of articulating such a drive?

Before this, however, the question is posed in slightly different terms by René Thom in *Structural Stability and Morphogenesis*[219]: "if evolution is governed by chance, and mutations are controlled only by natural selection, then how has this process produced more and more complex structures, leading up to man and the extraordinary exploits of human intelligence" (1972: 290). Again, there must be the case in which "control constraints"

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[218] E.g. see: Ott, E. (2002) *Chaos in Dynamical Systems*. Cambridge: Cambridge University Press.

[219] Nature for Thom renders a ''catalog' of forms, which present their own course, emerge, come into conflict with each other, fade away and undergo continuous evolution. The program presented in *Structural Stability and Morphogenesis* is superbly summarised by Espinoza:

> Thom makes an effort to combine the theoretical tools of the theory of dynamical systems (dynamic genesis of forms) and differential topology (static genesis of forms) to explain catastrophes or discontinuity of the regions where they produce abrupt changes of state, of the edges or boundaries of solids, phase transitions, etc. [. . .] The form organizes the matter, giving it unity. Nothing that exists is reduced to the actual being, since the actual being comes out of the virtual world. The potentiality is interpreted geometrically as a singularity. In a topological sense, a singularity appears when the points of a surface are projected on top of one another, while the surfaces are topologically deformed (in a few words, topology is the study of the properties of the objects that are invariant by a continuous transformation). The being-in-action is interpreted, in turn, as the development that stabilizes the description of a singularity. (1995: 322. Our translation from Spanish)

(Pattee, 1973: 55) enhance variability and freedom to a certain extent. Thom speculates: “I think […] there are formal structures, in fact geometric objects, in biology which prescribe the only possible forms capable of having a self-reproducing dynamic in a given environment”. He contends: “[a]ttraction of forms is probably one of the essential factors of evolution” (1972: 290-291). The question would remain, however (as Juarrero points out): “[h]ow to decrease randomness and entropy while simultaneously increasing the potential variety of messages?” we would be talking of a “constraint that curtails randomness without eliminating disorder altogether so that the possibility of new messages is retained.” (1999: 136).

Our proposal will be the term “noxiopoiesis” understood as a process of increasing production of complexity reliant on context sensitive enabling constraints. This *violence from within* (evocated by the *noxia*: the injurious act) is at the *core* of the act of ripping apart the angst of what seems to be the necessity of ‘natural’ ties and restrictions by enabling the system to functionally integrate (and take advantage of) noise.

These reciprocally determined (between functional randomness and dependance on the state of a system on its history) processes of individuation describe a positive feedback loop that contributes to the endless growth of complexity, but does not collapse thanks to the control constraints caused by (path-dependent) “hysteresis”.[220] These processes draw an asymptotic[221] trajectory that illustrates the recursive nature of our cognitive processes. The ‘making sense of’ operation we produce every time noise irreversibly morphs the field of knowledge, knowledge precisely in the direction of making, of poiesis.

This description of noise as enabling constraints, this noxiopoiesis, contrasts strongly with the limited picture provided by the use of computational metaphors. It is then time for us to examine on the basis on which assumptions these metaphors operate and what are their limitations when accounting for an info-computationalist (pancomputationalism + paninformationalism) picture of the world.

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[220] In a system, hysteresis causes the output value to depend on the history of the input. It makes explicit the system’s dependence not only on its current environment but also on its past environment. This dependence is present, precisely because the system can be in more than one internal state.

[221] 1672 *Philos. Trans.* 1671 (Royal Soc.) 6, 3065. “Asymptotick spaces..comprised between two lines, which being infinitely prolonged do never meet.” P*hilosophical transaction*s · 1665–1752 (vols. 1–46). London: Printed by T.N. for J. Martyn and J. Allestyry, Printers to the Royal Society, 1666-1886.

7.6: Computational Metaphors (and their Limits)

7.6.1 Hierarchical Order

Granted such operations as described in 7.5.2, nevertheless the question remains] [as to] how are we able to recognise that we are in fact faced with a complex pattern, or when we are actually observing a series of complex dynamics?

One prima facie credible criterion would be that we recognize complexity when we confront not simply plurality of parts (as in AIC) but when these parts form ordered hierarchies. For example, Herbert Simon definition stipulates that hierarchy entails "a system that is composed of interrelated subsystems, each of the latter being in turn hierarchic in structure until we reach some lowest level of elementary subsystem" (1962: 468). In slightly different terms, Grobstein maintains that a "[h]ierarchical order refers to a complex of successively more encompassing sets" (1973: 31). It is noteworthy to highlight that this recursive description is driven by merely epistemological interests; it states how a system may be observed or described. Ontogenetic[222] aspects, for instance: how the system is causally generated or organised, are not considered. Accepting the causal perspective allows the differentiation between two different approaches regarding "hierarchy construction", namely: top-down and bottom-up. In a top-down, planned or designed hierarchy, the system exists as an *a priori* potentiality (à la Plato) of an abstract transcendent form, i.e. as 'structure'. A product of our mind (concept) prepared for the next actualisation in matter. Under this organisation, the boundary between the system and its environment is predetermined. By contrast, in a bottom-up, evolutionary or emergent hierarchy: the system comes into being as an *a posteriori* teleological actuality. Telos (function) and form (structure) emerge as a result of the formation of a coupling connection between the constituent elements. Grobstein maintains that systems turn out to be dissociable and distinguishable from their environments

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[222] Regarding our preference for the use of "ontogenetic", rather than metaphysics when talking about causality, see: Grant, I.H. (2020) "All the principles of being and becoming": Schelling's ontogenetic hypothesis. *Rivista di estetica,* 74. As well as Recapitulation All the Way Down? Morphogenesis without Final Form in Kielmeyer's 'new epoch in Natural History' in: Azadpour, L. and Whistler, D. (Eds.) (2020) *Kielmeyer and the Organic World.* London: Bloomsbury. "Ontogeny" occurs only when some being arises; it has the virtue of universalizing ontic nominalism without making a substance metaphysics of Being. The advantage of this usage in our present case is that ontogeny not only allows but necessitates an address to causality.

when a relative or partial causal closure is constituted in the systems, but system-discreteness is contingent upon state definitions of complexity (as in 7.4) i.e. on a substance not a process-based account of systems.

In computer science, we do need to differentiate system hierarchies from system partitionings: hierarchies (both of the set of subsystems and their interrelations) need to be determined, while in the case of partitionings, the determination of the subsystems alone is enough. Rosen argues (1977) that it is not possible to consider an objective (physically motivated) decomposition. Even though Simon (1962) maintained precisely the opposite by 'invoking' the role of what may be understood as Kantian synthetic a priori (a sort of categorial filter in this case) in perception as well observation:

> The fact, then, that many complex systems have a nearly decomposable, hierarchic structure is a major facilitating factor enabling us to understand, to describe, and even to "see" such systems and their parts. Or perhaps the proposition should be put the other way round. If there are important systems in the world that are complex without being hierarchic, they may to a considerable extent escape our observation and our understanding. Analysis of their behavior would involve such detailed knowledge and calculation of the interactions of their elementary parts that it would be beyond our capacities of memory or computation. (1962: 477)

If we do not have access to a definition of degrees of such physical complexity, an exercise of simplification is performed and justified *in the name of abstraction*. Can we thus rely on the definitions of levels of complexity provided by computer science? It was proposed by Wolfram (1984), based on the qualitative behaviour of cellular automata[223], that the appropriate computational standard for modelling the aforementioned region *at the edge of order and chaos*, is the Universal Turing Machine (UTM). The Turing machine (TM)[224] is

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[223] See chapter 2 for a characterization of Wolfram's cellular automata.

[224] A Turing machine can be equated to the so-called "universal computer" or "universal automaton", which is an abstract mechanical system (mechanical in terms of randomness in the machine itself, nevertheless, we can think about the use of random programs in a deterministic machine) that can be pictured as following: four elements; a tape as long as needed, a read/write head, a set of symbols, and some rules. The symbols can be anything, but are usually represented as numbers; we can have as many or as few symbols as we want. The tape can present any initial symbols on it, anywhere (or everywhere) on the tape; this is very relevant. The rules are of the kind of: "if the value under the head is *a*, then 1) write symbol *b* (which may be the same as *a*), 2) move the head left or right one spot, and 3) either finish the program or continue operating". These are basically all the rules. This has proved that: a very simple computer can be made to be just as theoretically powerful as the computers that surround us today. In other words, any computation that our smartphones or laptop can also be performed by the Turing machine given enough time, enough tape length and the appropriate set of rules. Even more striking is the fact that, given a particular and appropriate set of rules, the Turing machine can perform *any* computation. The computation to perform is thus defined by the initial state of the tape. The smallest Turing machine (in terms of number of states and number of symbols) would be the smallest set of symbols and rules

perhaps the most common type of automaton. A universal binary computer must recognise any binary program. From the physical point of view, if we characterise a computer as an automaton, the automaton would be the dynamical system and the program its initial conditions.

Digital pancomputationalism[225] expressly argues that nature, or the *universe is a TM* (see e.g. Denning, 2007). This presents very obvious conceptual problems as expressed by Piccini:

> If pancomputationalism is true and thus everything is a computing system, then minds are computing systems too. But at the same time, computation ceases to be a specific kind of process among others. If the fact that minds are computing systems follows trivially from the fact that everything is, it is unclear how computation could explain how minds exhibit their peculiarly mental characteristics. In other words, if everything is a computing system, it is unclear how computation could have anything interesting to do with inference, rationality, executing instructions, following rules, or anything else specific to explaining mental phenomena. (2007: 95)

But there are other species of pancomputationalism (limited, unlimited, ontic, strong, limited, weak, causal, etc. see. e.g.: Piccinini, 2017 and Anderson and Piccinini, 2017) that overtly depend as well on Turing's notions of computing assuming algorithmic procedure (Turing, 1936). Thus, we need to address pancomputationalism as accomplished *Turing pancomputationalism* and we need to understand its rudiments.

The Church-Turing[226] thesis establishes that: if a computer has certain basic properties (understood as the Turing machine), it will be able to compute anything that can be computed -given sufficient time and resources. Computers are input-output machines, mathematically isomorphic, where each input generates a single output. Computers, therefore are predictable, algorithmic, computational. This contrasts heavily with the *unpredictability of the world*. And it should be self-evident that at each step, the number of possible future states increases dramatically. Today humans have transformed the world at a much higher and unpredictable

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that would be necessary to constitute a UTM. Even though a Turing Machine has the capacity to operate anything that a much more powerful computer would compute (although the UTM would be much slower), the fact that Turing never meant for one to be made is remarkable. In spite of this, today we say that a computer programming language is *Turing complete* when it proves to be robust and efficient, in the way in which it can compute anything that a Turing machine *could* compute.

[225] A physical world is isomorphic to a digital (or mathematical in its weaker version) structure. See: Beraldo-de-Araújo, A. and Baravalle, L. (2017) The Ontology of Digital Physics. *Erkenn*, 82 (6). pp. 1211–1231.

[226] A very good overview of the Church-Turing thesis can be found on: Soare, R.I. (2009) Turing Oracle Machines, Online Computing, and Three Displacements in Computability Theory. *Annals of Pure and Applied*. 160, 3. pp. 368-399.

velocity than any other multicellular organism has ever done, or than the world of crystal structures has ever achieved. How is it possible to conceive the universe as a “computational system equivalent to a Turing Machine?” (Floridi, 2009: 175).

TMs operate using what are called formal languages. These consist of words (finite strings) whose letters are taken from an (finite) alphabet. Well known instances of formal languages are for example the programming languages we currently use in computer science. These are included in the category of formal languages known as “context-free languages”. Turing orthodoxy (that is: computation as a logically closed system that takes place between input and output) has been challenged by Crutchfield (1994) and Negarestani (2020), pointing out that rather than investigate within the boundaries of the TM, maybe, it is more fruitful (if *all* processes were to be described as if they were computational processes) to pay attention to the whole hierarchy of machines that computation theory offers us. Traditional computation theory supplies a splendid context in which models of machines or automata are related to the languages they identify, which are (at the same time) produced by their corresponding grammars. We know this hierarchy as the “Chomsky hierarchy”.

Departing from previous work by Axel Thue, Alan Turing and Emil Post. Noam Chomsky’s talk at the 1956 Dartmouth Summer Study Group on Artificial Intelligence (Li and Vitanyi, 1997: 308), introduced the idea of a formal hierarchy of languages in accordance with the types of computing machines necessary to recognize them (Chomsky, 1956). The Turing machines constitute the top of this hierarchy. Chomsky presented a number of extensive abstractions and simplifications of the empirical sphere of natural language.

He offered a ‘barometer’ for linguistic theories that establishes a minimal limit of descriptive adequacy. Chomsky (as Lee explains) defines “syntax as...

> the set of rules that define the spatial relationships between the symbols of a language, various levels of language can be also described as one-dimensional (regular or linear), two-dimensional (context-free), three-dimensional (context sensitive) and multi-dimensional (unrestricted) relationships. From these beginnings, Chomsky might well be described as the ‘father of formal languages’ (1995:164)

As explained by Lee, Chomsky identifies four kinds of languages as parts of a hierarchy of four levels of growing complexity. The more complicated the language, the more intelligence is needed to transform the language into meaning: Type 3, regular, the simplest ones; Type 2 are context-free languages; Type 1 context-sensitive languages and Type 0: recursively enumerable languages, recognizable by a standard Turing machine. “Chomsky’s hierarchy” of syntactic forms (1957), was (and still is) extensively employed in the production of artificial computer languages. The huge triumph of this model (permeating from linguistics to theoretical computer science, and in recent years, molecular biology) implies that these abstractions were ‘carefully and appropriately’ produced, retaining the critical features of the structure of natural languages.

For our inquiry, it is important to note that natural languages are not random strings. For random sequences we can distinguish the complexity of the generator used in terms of Chomsky hierarchy. Truly random strings have no rules, no grammar. Non-random strings have rules; rules create patterns.

7.6.2: Heterarchical Processes

But what purchase does the notion of hierarchy have when a system is subject to perturbations? These “fluctuations” or “noise”, bring about a persistent perturbation to the system causing it to explore a “global state-space”[227] until it finds metastable states. These states coincide with the global, emergent structures (Heylighen, 1997). The system might need to restructure itself in order to survive. In order to be able to do such a thing, the disturbed elements must be capable of communicating with the neighboring components of the system. A precondition for this requirement would be a level-crossing of elements so it enables the feedback between them. This kind of connection offers to the components the opportunity of implementing bidirectional communication, and the amplification or attenuation of external inputs. All these procedures can lead to feedback. What we will examine now is how “heterarchy” permits such level-crossing relations, and it has a special

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[227] When modelling dynamic systems, a state-space representation is a mathematical model of a physical system consisting of a set of input, output and state variables determined by first-order differential equations. See: Hangos, K.M.; Lakner, R. and Gerzson, M. (2001) *Intelligent Control Systems: An Introduction with Examples*. Berlin: Springer. p. 254.

relevance for complex systems and in particular; the application of neural networks to artificial intelligence.

The notion of heterarchy was introduced (in contemporary history) by cyberneticist Warren McCulloch[228]'s in his short 1945 paper 'A Heterarchy of Values Determined by the Topology of Nervous Nets'. As Carole L. Crumley has explained:

> [h]e examined alternative cognitive structure(s), the collective organization of which he termed heterarchy. He demonstrated that the human brain, while reasonably orderly, was not organized hierarchically. This understanding revolutionized the neural study of the brain and solved major problems in the fields of artificial intelligence and computer design. (1995: 3)

Heterarchy has its etymological roots in Greek: *heteros* (the other, the different, ...) and *archein* (to reign, to govern, ...), i.e.: under the governance of the *other*. Heterarchy can be seen as a more appropriate term for an 'interdependent' or 'entangled' hierarchy. It can also be understood as co-ordination (like a network or fishnet) or, as "co-operation", and hence as entailing a virtue ethic. McCulloch's notion is highly remarkable insofar as it supplies a structure that attains the possibility of developing the concept of structural models with different patterns of organization. The heterarchy of which McCulloch talks is in fact our brain's organizational structure, that is to say: the human brain does not follow a hierarchical organization.

For McCulloch, a simple circuit of six neurons could produce behavior *unpredictable* from *any hierarchical theory of values.* McCulloch's developments of neural networks were in fact the model of Paul Baran's survivable packet ('block') switching network which is the landmark characterisation of the architecture the Internet exhibits in the present[229].

In his essay, McCulloch describes a simulation of decision-making and "circularities of preference" (1945: 93) in which a human brain has to select (perform value-judgements)

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[228] He is most famous for his paper with Walter Pitts: A Logical Calculus Immanent in Nervous Activity. *The bulletin of mathematical biophysics volume* 5. pp. 115–133 (1943). This work is greatly acknowledged as a foundational contribution for neural network theory, the theory of automata, the theory of computation, and cybernetics.

[229] See: Baran, P. (1960) Reliable Digital Communication Systems Using Unreliable Network Repeater Systems. RAND Corporation. Baran, Paul, and Stewart Brand. 'Founding Father.' Wired 9, no. 03 (March 2001).

between three possible ends. First, he created the map of a theoretical neuron circuit without any level-crossing. This produces a hierarchical structure in which the emergent order has a preference for one end over the others. In his words: “if a first is preferred to a second and a second to a third, then the first is preferred to the third” (McCulloch, 1945: 92); the underlying rationale for this, McCulloch indicates, is that this style of analysis reveals a “hierarchy of values” (ibid.) and that is possible to measure these values in agreement with some commonly accepted magnitude. McCulloch is trying to prove that on the contrary, there is “no common scale” (ibid.) with which we can measure values of this type. Thus, McCulloch proposes a more sophisticated simulation to determine a heterarchical topology of the nervous net. A neural network in which its organizational structure does not exhibit a hierarchical organization[230]. Thus providing a description model for natural phenomena such as brain activity.

The essential logical basis could be understood in the ideal case of just six neurons arranged in a circular configuration such that A would stimulate B and inhibit C. B would stimulate C and inhibit A. C would stimulate A and inhibit B. In his words: “Consider the case of three choices, A or B, B or C, and A or C in which A is preferred to B, B to C, and C to A” (ibid.).

What McCulloch is carrying out with this simulation is the kind of level-crossing he suggested in the first place, and this does not entail a contradiction in terms. He argues that in a network where at least three feedback loops are connected into a greater loop (the same number of connections Baran considers to create a ‘distributed’ network[231]) “[c]ircularities in preference, instead of inconsistencies, actually demonstrate consistency of a higher order than had been dreamed of in our philosophy” (1945: 93). He continues: an “organism possessed of this nervous system—six neurons—is sufficiently endowed to be unpredictable from any theory founded on a scale of values. It has a heterarchy of values, and is thus interconnectively too rich to submit to a summum bonum [highest good]” (ibid.). Douglas

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[230] The heterarchical organisation described herein, does not *only* operate at the neuronal level. It operates too at the level of the overall anatomy of the brain. It is common, for example, to characterise this anatomy in hierarchical terms (hindbrain, mid-bain, forebrain etc), and also to root this hierarchy in the supposed evolutionary order of emergence of these various parts of the anatomy. However, regardless of the relative temporal emergence of these anatomical parts or sub-systems, they are, in fact, connected heterarchically via numerous feedback loops. There is no real sense in which the cerebral cortex is hierarchically superior to the brain stem (fallacy of the ‘primitive brain’ within etc). Instead there appears to have been successive bifurcations of the system as a *whole* - systemic emergences succeeded by emergences, as these anatomical parts rewire themselves under adaptive pressures.

[231] See: Baran, P. (1964) On Distributed Communications. Santa Monica, CA: RAND Corporation.

Hofstadter, in his Pulitzer awarded book *Gödel, Escher, Bach*, states that a heterarchical system of this kind is a "program which has…a structure in which there is no single 'highest level'" (1979: 134). Heterarchies are then complex adaptive systems precisely because they interweave a multiplicity of criteria according to which performance may be evaluated, esteemed, or appraised.

It is easy to understand that the character of heterarchical processes cannot be ascribed to the transitions between initial and final states in the way in which they take place in chemistry and physics[232]. If we follow Simon's (1962) definition of hierarchy, all *physical* processes (transitions between two or more states) *are hierarchically structured*. But we should be wary of extending the fact that inorganic physical processes are hierarchically structured to *all* processes. For example, in the classical metaphysical notion of the "great chain of being" (Lovejoy, 1936), i.e. of discrete and ascending levels of being participating in a timeless absolute would render the restriction to merely physical processes something minor and ancillary, while demonstrating the problematic consequences of extending a single structure to all things. It goes without saying that noxiogenesis takes this to be false in fact and in principle, and hence will argue for a process account of augmenting complexity rather than for static structures of monolithic hierarchy.

Considering that hierarchy and heterarchy are not mutually exclusive classes of description, we can infer that the transitivity law[233] is legitimate for the logical description of both heterarchical and hierarchical process structures but it can only be implemented to hierarchical structures and not their heterarchical adjuncts. When we pay attention to hierarchical structures, we effortlessly recognize that even hierarchical structures are *only meaningful within* the framework of *processes*. For instance, we cannot create a discrete distinction between volition and cognition –and the other way around. Volition and cognition are processes that cannot be separated, i.e. they take place as a "parallel-simultaneously mediated co-existing processuality" (von Goldammer, Paul and Newbury, 2003: 5). We could argue that volition and cognition have to be understood as an *indivisible and interdependent mesh*, a reciprocal relationship of a hierarchical and heterarchical processuality.

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[232] Physical and chemical processes (in terms of state transitions) can be detailed (since the invention of calculus by Newton and Leibniz) by differential equations.

[233] The Logical Law of Transitivity holds that if a relation is transitive, then whenever a~b and b~c, you automatically have a~c. See: Schmidt, G. (2010) Relational Mathematics. Cambridge: Cambridge University Press.

Truth-definite logic is not appropriate for modelling a processuality which characterizes diverse points of view (various logical places) and which is defined by a parallel simultaneity of processes. All our mental processes (i.e.: reasoning, learning decision-making) are part of this class of processes. This could be seen as something exceptional and unexpected since we have been taught that the transitions between different states (as they take place in the world of chemistry and physics), which we designate as processes, can be mathematically depicted with differential equations[234]. This ideal of a sequence of points in time (which essentially defines the notion of differential calculus) has been so effective that it is employed as a description tool for different sorts of processes in: biology, finance, social sciences, and of course the biological neural networks that constitute animal brains. This notion of a sequential processuality appears as the result of a "given[235] axiomatic reality" that cannot be scientifically questioned since we have no alternative background and we are not able to conduct measurements of any other processuality. This could be seen as the consequence of an enigma of epistemic nature, at least in the contemporary world, where thought is governed by the natural sciences. It seems as if nowadays, as a byproduct of our positive-linguistic scientific language and logic, scientific reality is the only measurable reality. This is the neo-positivistic worldview: a (physical) state *is* or *it is not* (à la Parmenides) and if the state *is*, then it is plausible to characterise the transitions from an initial to a final state as an ordered sequence of transition states through the application of the immutable mathematical operations. Such is the tragedy of neo-positivism, the subordination of truth to a non-reference based system-internal ontology (as Tarski illustrates with the recursive definition of convention T as eliminating any need for truth by reference[236]) driven by an *operationalistic telos* deciding on the obtaining or non-obtaining of some being.

But again, what about modern computation? What are the boundaries of the extensive application of computational metaphors to explain human complexity?

The concept of heterarchy has drawn a lot of attention in a great deal of different scientific fields. The economic sociologist David Stark argues that McCulloch's research...

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[234] In order to contrast this idea that might be understood as a discrete ontology of temporal elements, we would recommend considering Kielmeyer's concept of time-particles: x is a time particle just when it conjoins incompatible differences at any level of analysis. See: Grant, I.H. (2020) Recapitulation All the Way Down? Morphogenesis without Final Form in Kielmeyer's 'new epoch in Natural History' in: Azadpour, L. and Whistler, D. (Eds.) (2020) *Kielmeyer and the Organic World.* London: Bloomsbury.

[235] This is a conceptual use of the word, in resonance with Sellars' myth of the given.

[236] See:Tarski, A. (1935) The Concept of Truth in Formalized Languages. *Logic, Semantics, Metamathematics*, Indianapolis: Hackett 1983, 2nd edition. pp. 152–278.

> led to the development of artificial networks as a new computing technology, which, in turn, fed back to the computational modeling of the brain. His idea of redundant network ties was important for the conception of reliable organization built from unreliable parts, laid the basis for the new field of "automata theory," and contributed to the fertile concept of "self-organization." "A Heterarchy of Values" is cited as an inspiration for non-Turing, or non-Euclidean, computing, most recently in efforts to develop biology-based computing. (2009: 29-30)

In contrast with a promising future led by McCulloch's influence in the novel field of hypercomputation[237]. Today, we use computers that operate based on the premise that all algorithms are provided by a sequence of instructions. All our available algorithms account for processes only in terms of state transitions, in other words, all algorithms can be typified by a sequence of ordered time points no matter what programming language will be employed for their execution. This is the reasoning behind the representation of all known algorithms within the function model of the Turing machine. This is what we understand when we describe an algorithm as a "Turing computable function"[238].

We are now in a position to turn to a fuller characterization of the problems of considering complex processes via the UTM, and to prepare the critique of such uses. The operation of a Turing machine is extremely rigorous sequentiality. That is: all (arithmetic) operations are performed in a (time) sequence of single steps where the transitivity property still applies. Simply put: according to the Church-Turing thesis only hierarchically structured processes/algorithms can be modelled and executed. Heterarchically structured processes/algorithms, by contrast, are not part of the Turing machines domain (the domain of our current computers) and this is one of the fundamental problems underpinning all conceptions made during the recent advances in Artificial Intelligence[239]: that any heterarchically structured processuality (such our brain activity) can never be modeled on the basis of a classical TM. It is possible, however to model actions and processes algorithmically with the interest of implementing the model into a machine (Kaehr, 2003), *but* for the domain of a (non-Turing) computer with mediated "contextures" (the particular arrangements of the constituent parts of their correspondent wholes) and we have to specify

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[237] Computational models that can provide outputs that are not Turing-computable.

[238] See: Cutland, N. (1980) *Computability*. Cambridge: Cambridge University Press.

[239] See: E. von Goldammer, Zeit-Mehrzeitigkeit-Polyrhythmie oder das polylogische orchestrion, in: Theorie – Prozess – Selbstreferenz, (Oliver Jahraus & Nina Ort, Hrsg.), UVK-Verlagsgesellschaft, Konstanz, 2003, p.129-185. E. von Goldammer, Betrachtungen über eine bekannte Unbekannte: Die Zeit, in: www.vordenker.de

some conditions which in fact do not exist in the domain of the Turing machines –a region with only *one* contexture. All transitions and/or processes within *one* contexture (linked together forming a connected whole), i.e., intra-contextural, are *hierarchically* structured while all inter-contextural transitions/processes, i.e., transitions and/or processes between *distinct* contextures are *heterarchically* structured. To some extent this is the characterisation of heterarchy within the linguistic context of polycontexturality[240].

In the 1972 text "A new approach to the logical theory of living systems" Gotthard Günther proposes a thought experiment[241]: think about a world where the events are limited to acoustic phenomena –sounds. In such a world, consciousness stands for consciousness of sound-events without arrangement or combination. Every single thing that occurs takes place as a sound-event in a total abstraction of other sense-data. Günther names such mono-sensorial consciousness and world: *contexture*. If we think about melodic sequences of sounds in music pieces. These connections are events made by sounds within a more general contexture of sounds. Günther names single contexts these kinds of events that comprise connections of elements of a contexture.

Klagenfurt further describes Günther's theory, clarifying that:

> [b]y 'contexture' we understand a bivalently structured area that in a logical analysis could be considered to be a logical system of the classical bivalent logic. […] a system is *polycontextural* if it consists of several contextures that are linked together through intermediating relations. […] In the simplest case a polycontextural system consists of three contextures, which can, if necessary, increase its complexity by adding further contextures. As new contextures are added, other new contextures automatically emerge, These are called connection-contextures and mediate the new with the old contexture. Thus the individual contextures are ordered among

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[240] The idea of an extension of classical logic to cover simultaneously active ontological locations was introduced by philosopher and logician Gotthard Günther (1900-1984). The theory of a Polycontextural Logic has its origins in Günther's research on Schelling and Hegel as well as the co-foundation of cybernetics working together with Warren McCulloch and Heinz von Foerster among others. He attempted to develop a philosophical system that combined the improved results of modern dialectic with formal logic, as well as a mathematics of dialectics and of self-referential systems –a cybernetic theory of subjectivity as an interrelationship between volition and cognition. See: Günther, G.: *Beiträge zur Grundlegung einer operationsfähigen Dialektik*. Bd.1-3, Hamburg, Verlag Felix Meiner, 1976-1980.

[241] G. Günther, "A new Approach to a Logical Theory of Living Systems" (unpublished manuscript in private possession of Dr. Rudolph Kaehr) available at www.vordenker.de.; Idem, "Negation and Contexture" (unpublished manuscript in possession of Staatsbibliotek zu Berlin – Preussischer Kulturbesitz) available at www.vordenker.de.

> themselves not hierarchichally but heterarchichally. Polycontexturality is therefore characterised by *intra*contexturality, the structural description of a contexture; *inter*contexturality, the description of the mediation between the individual contextures; and *discontexturality* as the description of the limit of contextures (2001: 140ff., our translation).

If we look at Peirce's understanding of semiosis as "an action, or influence, which is, or involves, a co-operation of three subjects, such as a sign, its object, and its interpretant, this tri-relative influence not being in any way resolvable into actions between pairs" (CP 5.484), then we can assert that Peirce would have been sympathetic to Günther's notion of polycontexturality –if it had been known to him in his time. The environment of the contexture would be what we are now calling the semiosphere.

Within *one* contexture (intra-contextural) the transitive property is legitimate and still applies. This is the domain of physics or the computer domain of the Turing-Church thesis. On the contrary, the inter-contextural processuality is non-transitive. It is not possible to apply the transitivity law, since it is just defined intra-contexturally (within a contexture) and not for transitions in the middle of contextures. Thus, the inter-contextural processes or transitions cannot be explained in terms of traditional sequential time steps. These transitions or processes constitute McCulloch's co-ordinated, i.e., *heterarchical processes*.

Since it is not possible to have 'entirely' inter-contextural processes like discrete substances which can be separated, or hierarchical processes (inorganic physical processes) which can be perceived as such, this fact entails that all mental processes need to be rendered or modelled as (dialectical) interrelationships of hierarchical and heterarchical processes. Actions, at all times can be explained intra-contexturally, i.e. within a contexture. Once again, this is the domain of chemistry and physics, their quantitative measurements, the domain of modern computers and the epistemic sphere of positive sciences.

The process of decision as such (that is: before a designation takes place) is fundamentally a result of inter-contextural, non-designative transitions and/or processes. Our thesis is aimed towards the production of a process metaphysics of noxiogenesis in contrast to the discrete-state metaphysics of pancomputationalism: any decision as a whole is a process or (even better) a processuality (i.e., many processes running at the same time are concerned) and not a state, non-designation then entails a negation of something in relation to something else, i.e., a negation of a "standpoint" (a contexture or compound contexture) which is only significant in connection with other standpoints. Accordingly, a concatenation of negations or intervals of negations are generated for which Günther coined the notion of "negative language" (*Negativsprache*), to open up the space between the contextures. It is precisely this emancipation from the dictates of mono-contextural logic that sets the stage for an observation of complexity.

The use of heterarchy as an additional type of explanation to the popular and still 'hegemonically' used hierarchical type (once the complementarity of the two notions is acknowledged) prompts a more accurate scientific characterisation of both notions. A comparable advance could be the historical shift in the field of physics from Newtonian to quantum mechanics in the 1930s. The fact that the notion of "heterarchically structured processes" have been disregarded substantially by the mainstream fields of science, may be due to the ambitious techno-social, economic and scientific implications entailed by the modelling and application of McCulloch's "heterarchy of values" – the interaction of heterarchical and hierarchical processualities. There is no possibility of measurement of the reciprocal relationship between heterarchically and hierarchically structured processes just as we conduct measurements of (for example) the temperature of the cosmic microwave background. These processes escape any positive-linguistic model of scientific language, to use Gunther's terms. Given the fact that all mental processes are part of this class of processuality, which is clearly subject to living systems, we can deduce that life is distinguished, for the most part, by this kind of processuality.

A process-metaphysics or noxiogenetic account of complexity must be heterarchical, thus ruling out hierarchical (decision-tree, AI *application-apt*) modelling of complex processes, confirming intuitive or - better *experiential* sense of everyday complexity with a theoretical model responsive to this. A process that mediates a plurality of irreducible systems in an exchange relation of context and contexture.

In view of the aforementioned supremacy of natural sciences; of the conviction that only measurable phenomena are close to reality (an idea deeply-rooted in our scientific reasoning, particularly in the Western world[242]), we could say that speculating about such processuality, remains an insistent and important intellectual challenge.

7.7. Conclusion

7.7.1 Heterarchy, Complexity and Process

Since the challenge remains, there is a clear case to be made for the fruitfulness of the conceptual structure of heterarchy, in particular as regards the way in which it supplies different models of conceptualizing interrelationships of different levels in complex systems, at the same time as retaining the neutrality regarding the position of each level.

Nor are we alone in making such claims. For example, in ‘A Dialectical Critique of Hierarchy’ (1987), the anthropologist Carole L. Crumley presents a review of the presuppositions underpinning the conventional apprehension of structure in state societies. Crumley is interested in particular linguistic abstractions predicated on binary oppositions (as for instance, between order and chaos) that “[in-]form” (1987: 156) and, in accordance, configure our mental perception of social patterns of organization. Binary opposition generally grants privilege to one... over others; in other words, binaries constitute semantic hierarchies based on *both* socially arranged as well as subjective value judgments. Crumley argues that these hierarchical structures are *de-formations* of abstract and complex patterns, frequently reaffirmed through the reiteration of “metaphors for social relationships” (ibid.). Crumley not only wants to disclose the metaphors veiled under these binaries, she also contributes to the conceptual domain of the heterarchy structure, as a potential point of departure for a new and different understanding of the social levels of organization. According to Crumley, “structures are heterarchical when each element is either unranked relative to other elements or possesses the potential for being ranked in a number of different ways” (1987: 158). Crumley’s final remarks in her essay are relevant not only as a process-philosophical complexity theory, but as well for what we understand about the present “complex society”. “[H]ierarchy is a controlling model in complex society” (1987: 159). As a matter of fact, an algorithm modelled on that basis can rapidly adapt into any different

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[242] Aristotle makes this point in the *Physics* (184a25-6: “the concrete whole is more readily cognizable by the senses”; see also his statement of discrete ontology at *Physics* 187a34: “The universe is composed of a plurality of discrete individual entities.”)

species: hierarchy (potentially) constitutes a controlling model for any complex system. Heterarchy, on the contrary, is a reorganizational model with no lowest or highest level: neither ground (ultimacy) nor finality. It functions in line with changing level-crossing principles in complex systems. This gesture of reorganization contributes to the robustness of the linguistic and spatial abstraction of the eccentric loop as a conceptual structure, with the purpose of reorganizing two seemingly different domains (art and mind) in an entangled, co-ordinated, non-hierarchical relation. “Heterarchy” (Stark writes) “is neither harmony nor cacophony but an organized dissonance” (2009: 27). He continues:

> Dissonance occurs when diverse, even antagonistic, performance principles overlap. The manifest, or proximate, result of this rivalry is a noisy clash, as the proponents of different conceptions of value contend with each other. The latent consequence of this dissonance is that the diversity of value-frames generates new combinations…Because there is not one best way or single metric but several mutually coevolving yet not converging paths, the organization is systemically unable to take its routines or its knowledge for granted. (ibid.)

Nonetheless, for the reasons mentioned above, it does not come as a surprise that recent examples from the field of computer science (that attempts to construct computer systems that emulate human problem solving behaviour with the goal of understanding human intelligence) are constructed on the basis of precisely the Church-Turing-thesis and consequently in hierarchical process structures. In a thoughtful and incendiary conversation of his book *The Emperor’s New Mind* (1990) with some of the most well-regarded figures of the AI research field, Roger Penrose explains this particular issue in the following words:

> It is a remarkable fact that any computational process whatever (that operates with finite discrete quantities) can be described as the action of some Turing machine. This, at least, is the contention of the so-called Church-Turing thesis, in its original mathematical form. Support for this thesis comes partly from Turing’s careful analysis of the kinds of operation one would actually consider as constituting a computational or algorithmic process, and partly from the striking fact that all the various alternative proposals for what an “algorithm” *should* mean (put forward at around the same time by Church, Kleene, Gödel, Post, and others) have turned out to be completely equivalent to one another. Some of these proposals had the initial appearance of being completely different, so their equivalence is a strong indication of the fact that they are merely alternative ways of describing an absolute abstract mathematical concept, that of computability (which is independent of any particular realization of it that one may care to adopt.). (1990: 646-647, emphasis added)

7.7.2: Ethical Prognosis of the Discretization of Complexity

Penrose's grammar reveals, in its use of "should" (thus acknowledging the "is not" implicit in this characterization), an untheorized yet crucial, normative dimension of the problems we have been examining and to which we now turn. 30 years later after the publication of his classic, it is pretty evident (given the present moment we are living in) that entirely new methods of critically addressing our extremely-technologically mediated present (and immediate future) are required. If the complexity of such highly interwoven process structures take place; not only in our minds but also within our societies (societies that are in turn being modelled by algorithmic milieu of communication and control), we need to acknowledge the limitations of computational metaphors –and in particular hierarchical structuration. The heterogeneity of the contemporary algorithmic approach of computational network science, does not suffice to account for the actual human complexity and non-hierarchical categories of identity, sociality and sensemaking.

The expiration date of hierarchical structuration can be seen in the new types of decentralised financial transaction and cryptocurrencies (here, the use of blockchain technology[243] as a decentralized, distributed, and frequently public digital ledger is fundamental) as well as the low-cost manufacturing shift supply chains (even treasury and financing operations are being decentralised as well) approaching an ever-more complex and fragile model of logistics and coordination. The tendency towards increased hidden regimes of complexity behind technological design and practice is omnipresent as well in contemporary exercises of algorithmic warfare (Wilcox, 2017), the use of biometric technology for border control security (Csernatoni, 2018; Kloppenburg and van der Ploeg, 2020) along with the life and medical sciences (Mehta et al., 2019). All these examples of technoscientific research might be boosted and accelerated with security applications due to the present COVID-19 pandemic.

The fatuous pancomputationalist appeal to a faith in the digital and a purely speculative assertion of planck-scale (hyper)-computation (a computation that can generate spacetime itself - a purely transcendental notion which is what renders it speculative in the trivial sense)

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[243] For a comprehensive introduction to blockchain functionality see: Iansiti, M. and Karim, R.L. (2017) The Truth about Blockchain. *Harvard Business Review* 95, 1. pp. 118–127.

is armchair philosophy and barely worthy of serious critique. However, the volume, velocity and horsepower of planetary-scale computations is, according to many examples (Morgan, 2018; Deibert, 2019) re-arranging the balance of power and is allegedly responsible for drastic reversals of previously stable political relationships[244]. Surpassing the 'mere' configuration of the modes of the present, these operations of co-constitution have been closely bounded to the idea of the "future". The fascination with perceiving the future via technoscience still is a conventional approach that Hannah Arendt already advised against more than half a century ago. Substituting all moral and eschatological belief with particular conceptions of technoscientific advance for the future, deprived of history and the sphere of experiences, yet troubled with Promethean ideals, such a future was hollow, senseless, and impossible in the last instance (Arendt, 1961).

The big hopes for big data, permit (through globally interconnected surveillance systems) the promotion of the idea that just 'more data' can serve as the remedy to our present social and political uncertainties. Throughout the delegation of our thought (Leander and Waever, 2019) to algorithms in the: understanding, evaluation and construction of our social world, we are ostensibly modifying the challenge of the (in)security of the technological 'advances' we are living. This "idealised discreteness" willingly compresses to a split second what is in fact "a process and movement, rhythm and relation[s]" (Grove, 2019: 63) to the prejudice of those standing in the liminal space, "those more subtle connections or resonances whose effects are felt but not discrete are overshadowed by those relations we can chart and measure" as Grove (ibid.) lately criticised. In the current deluge of data, we are individuals at war against entropy. Like Maxwell's demon, we are forced to wage an uphill battle against the irreversible: disastrous global warming, financial collapse, psychosocial disorders etc. In order to ensure a 'humane' fight, we have to seize the means of computational complexity. I am not calling for a naïve government/state control, but rather, humans' promethean ambition (as social project) taking control of the means of computational complexity in order to orient ourselves towards self-emancipation.

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[244] Cambridge Analytica did work for Leave.EU on the EU referéndum in 2016 illegally collecting online data of up to 50 million Facebook users and may have altered the outcome of both the U.S. 2016 presidential election and the U.K.'s Brexit referendum, nonetheless, their influence in the result is uncertain. See: The Cambridge Analytica Files [online]. Available from: https://www.theguardian.com/news/series/cambridge-analytica-files [Accessed 16 June 2020], ongoing investigative reporting from The Observer/The Guardian, beginning 17 March 2018, part of News: Cambridge Analytica beginning a year earlier.

Conclusion

> Religion often partakes of the myth of progress that shields us from the terrors of an uncertain future
>
> *Dune* (Herbert, 1965: 502)[245]

In the desert, surrounded by a large mass of wind-blown white noise, one becomes aware of the infinite, and the only possible definition of what has no beginning nor end is God.

Perhaps religions were born in the desert because man there, in the middle of unfathomable multiple horizons, needs a limit. In a sort of first step towards the volitional production of *meaning*, since inherently *there is no given one*. After Sellars, epistemology at last begins to catch up with what Kant means by spontaneity - i.e. production! That is the reason why Goodman's worldmaking thesis is important: it amplifies the consequences for epistemology of eliminating givenness - and this is where all epistemology since has been. Hence inferentialism emphasizes the "making" in "making explicit". Making, that is, required if we are to make good on epistemic non-givenness. We can understand evolutionary conceptual frameworks as a variety of pancomputationalism, implying that the world can only compute and take the shortest route to heat death, the detour of evolution as a local solution to expenditure just happens to be that shortest route. The semiosphere that (like God) *places limits* on the former also places limits on the latter.

Plato's *Timaeus* description of what the "artificer"[246] did in bringing order out of noise is manifest in Whitehead's words: "for the Timaeus, the creation of the world is the incoming of a type of order establishing a cosmic epoch. It is not the beginning of matter of fact, but the incoming of a certain type of social order" (1978: 96). Arguably, the mono-contextural control tendency described in the last chapter begins with Plato's *Republic* and the hierarchy

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[245] Thanks to Patricia Fraga for drawing my attention to this passage.

[246] In the Timaeus, Plato discusses the demiurge or "artificer" (28a ff), i.e. divinizes the craftsman; it is in the Statesman that the Plato adds to this "demiourgou" that it is "the composer of the universe" (273b), that is, as an artificer rather than as the 'creator-god' of the monotheists. Thus it is a creator - only "to the extent of its "power [dynamin]" - of order when the movement is forward, or of "disorder [ataxias]" (273b) when "the Steersman [kubernetes] of the world... made the world turn backwards"" (272e).

of the soul/polis. By bringing order to the environment, within the borders of the polis, a space of civilisation is allegedly safe, predictable, disciplined, ordered, and what remains outside of the polis (the natural world with all of the forces that it exhibits) is rendered a place of risk, of the wild, of noise, and chaos. The argument at the heart of this thesis is the idea that the soul/polis is always an irreducibly complex emergent inter-contextural outcome. The paradoxical issue arises when we realise how capitalism exploits not only inequality but also uncertainty and risk: "[c]onstant revolutionizing of production, uninterrupted disturbance of all social conditions, everlasting uncertainty and agitation distinguish the bourgeois epoch from all earlier ones" (Marx, 2000: 248) in order to basically sell us the fantasy of certainty, prediction, control and order. This is opposed to the noxiopoiesis proposed here: hence the complicity of classical cybernetics with the destruction of creation. It is, that is, no accident that cybernetics' first task was to target and eliminate future states of a (missile) system.

In this thesis, a renewed understanding of noise beyond dominant reductive readings has been presented. I have attempted to develop an *asystasic ontogeny of noise*. Due to the fact that we live in a world whose complexity surpasses any attempt at definitive conceptual determination, any hope for a system which could be complete in itself is revealed as vain. Having archaeological simples is a state common to complex systems that by definition are irreducible to their starting points, *but,* simples must be products and not sources of complex systems because there is no system that can obtain that successfully recollects its emergence. Precisely for this reason, a process metaphysics of *noxiogenesis* is posited in contrast to the discrete-state metaphysics of a reductive info-computationalism that aims to eventually complete a theory of the universe that can be formulated in computational terms.

In opposition to neo-positivist ontologies that decide on the obtaining or non-obtaining of some being, the multi-value processes it has been urged to consider in this thesis, obtaining and non-obtaining are amongst the indiscrete quantity of system-possibilities. I have not proposed a manichean characterisation of noise in here as the enemy of information nor a simplistic mystification of its disruptive potentialities, since it is that very manichaeism, as an artifact of classical cybernetics, that is responsible for having rendered noise informationally heretical. The concept of noise is necessary in our understanding of nature regardless of one's attitude towards determinism. Our understanding of noxiogenesis as the ground for the constant transformation of possibilities into actuality, entails a conception of indirect systemic pressures concerning a plurality of environments, based on discontextural (disjunct) and contextual relations. These relations are an evident manifestation of the fact that "[a] partially understood pattern is more definite as to what it excludes than as to what its completion would include [... for which] there are an infinitude of alternative modes." (Whitehead, 1938: 72). *Patterns*, that is, *are projected regularities*, not a discrete reality. This is precisely because the emergence of an X is an event local to what becomes the landscape within, and it contrastively arises. Noise is not only perturbation in communication, rather it is the message itself –that wants to be unveiled. It is noise that makes the message recognisable instead of invisible. It is through noise that the very notion of morphogenesis (in its most general understanding as the processes by which order/form is created) is instantiated. But information is different from noise because information is ascribed to certain particular codes. What makes noise irreducible, is that, for example, any organism is far too complex for genes to encode *a* specific outcome.

Should we be able to "encode for specific outcomes", we would be able to attribute predictive accuracy to living systems, yet the current predominance of epistemic probabilism dispels this Maxwellian fantasy. Thus, while today researchers and practitioners of statistics repeatedly declare that their results are above all probabilistic projections (not deterministic), policy/decision-makers (with the complicity of some data scientists and machine learning experts) conveniently neglect this fact. Still, demonstrating the impossibility of total computational prediction/control of mind/society/biosphere, must not undermine the necessity for resisting such efforts. To all intents and purposes we end up becoming potentially coextensive with the data-constellation that is projected. Externalising uncertainty (and hence, *noise*), countless species of data-driven "social scores" (social credit system[247], academic grading[248], risk scores[249]) as well as profit-led and military pattern-of-life surveillance affect the daily lives of *real* people. Not only social hierarchies but the *production of the future* as such is being radically reformatted by ranking, filtered, and classified without acknowledging the irreducible disruptive nature from which these very

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[247] See for instance China's social credit system: Campbell, C. (2019) How China Is Using Big Data to Create a Social Credit Score. *Time*. [online] Available from: https://time.com/collection/davos-2019/5502592/china-social-credit-score/ [Accessed 21 September 2020]

[248] See:Kolkman, D (2020) "F**k the algorithm"?: What the world can learn from the UK's A-level grading fiasco. LSE blogs. [online] Available from: https://blogs.lse.ac.uk/impactofsocialsciences/2020/08/26/fk-the-algorithm-what-the-world-can-learn-from-the-uks-a-level-grading-fiasco/ [Accessed 21 September 2020]

[249] See the British Medical Association "scoring mechanism to help you quantify your biological risk" during the COVID-19 pandemic [online] Available from: https://www.bma.org.uk/media/2768/bma-covid-19-risk-assessment-tool-july2020.pdf [Accessed 21 September 2020]

projections emerge in the first place, nor seem to provide sufficient (if there is any) accountability for the fiascos of their algorithmic procedures.

In light of the arguments presented in this thesis, we have seen how some species of hard determinists entertain randomness, but they all do so on the basis that it is ultimately either an epistemological artifact of heat death (as a sort of byproduct of the fact that there are a lot of degrees of freedom to work with, and only finitely many constraints before heat death), or a limit to the transmissibility of information –as it has been shown in the first two chapters. They each seek to identify what we might call "passive randomness" and not what I posit here as an "active randomness" in its ontological dimension, randomness that goes beyond unpredictability in any epistemological sense, or of outcome (lack of pattern, as in the thermodynamic sense), but a generative randomness that results in a universe in which *more than one outcome* is really possible, without any prior determination. In fact, noise as intractable ontological randomness limits the scope of determinism –what irony this is, given that determinism sought to put limits on noise. To establish on purely 'scientific grounds' whether ontological randomness exists would require us to sequence the universe *in full.* Such is the paradox of the refutation of ontological randomness by science: a scientific notion that cannot be *completely* studied by science. We need to agree with those who argue (Thom, 1983) that determinism in science *is not* something given, it is indeed *a conquest*, and those "*who would know the world must first manufacture it*" (Kant, 1993: 240), there is an insuperability of the situation in which epistemology finds itself following the critique of the given. But we must accept the fact that the refutation of randomness *will never be complete.* Instead of finishing with an end to noise, the noise of incomplete and repeated finishings becomes deafening. Asserting this does not entail any antiscientific attitude, quite the contrary, it serves as the source of the greatest confidence in methodological naturalism, not because it presents a limit on the sciences' disproportionate ambition, but because the proper practice of science is presented in this asymptotic vector.

The interdisciplinary and contemporary salience of noise concerns a necessarily unlimited number of fields the theoretical and experimental investigation of which is a problem of universal importance. Fully interwoven in the processes that fuel existential risk, understood not only as risk of extinction but also as the dramatic decimation of the humanist project detailed, *inter alia*, in Foucault's image of the ocean erasing the image of humanity from the shores of history[250], the study and poietics of noise are aprecondition for the future's possibilities to be explored.

Bibliography

Abbott, D., Davis, B.R., Phillips, N.J. and Eshraghian, K. (1996) Simple derivation of the thermal noise formula using window-limited Fourier transforms and other conundrums. *IEEE Trans. on Educ*. 39, 1. pp. 1–13.

Abraham, R. (1994) C*haos, Gaia, Eros: A Chaos Pioneer Uncovers the Three Great Streams of History*. New York: Harper Collins Publishers.

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[250] See: Foucault, M. (1970) *The Order of Things: An Archaeology of the Human Sciences*. Pantheon Books: New York.

Alberts, D.S., Czerwinski, T.J. and National Defense University (Eds.) (1997) *Complexity, global politics, and national security*. Washington, D.C: National Defense University.

Amsterdamski, S. et al. (1990) *La Querelle du déterminisme: philosophie de la science d'aujourd'hui*. Paris: Gallimard.

Anderson, C. (2008) The End of Theory: The Data Deluge Makes the Scientific Method Obsolete. WIRED. [online] Available from: https://www.wired.com/2008/06/pb-theory/ [Accessed 18 April 2020]

Anderson, M.L., Richardson, M.J. and Chemero, A. (2012) Eroding the boundary of cognition: implications of embodiment (1). *Top Cogn Sci*, 4. pp. 717–730.

Anderson, N.G. and Piccinini, G. (2017) Pancomputationalism and the Computational Description of Physical Systems. [Preprint] Available from: http://philsci-archive.pitt.edu/id/eprint/12812 [Accessed 18 April 2020]

Arendt, H. (1961) *Between Past and Future, Eight Exercises in Political Thought*. New York: Penguin Classics.

Astbury, N.F. (1948) The Moving Coil Galvanometer as a Circuit Element. *Proceedings of the Physical Society*. 60. pp. 590-597.

Atamer, E. (2011) Dissipative individuation. *Parrhesia: A Journal of Critical Philosophy*. 12. pp. 57-70.

Atlan, H. (1972) *L'organisation biologique et la théorie de l'information*. Paris: Hermann.

Atlan, H. (1974) On a Formal Definition of Organization, *Journal of Theoretical Biology*. 45. pp. 295-304.

Atlan, H. (1979) *Entre le cristal et la fumée: essai sur l'organisation du vivant*. Paris: Éditions du Seuil.

Atlan, H. (1981) Hierarchical self-organization in living systems. Noise and meaning. In Zeleny, M. (Ed.), *Autopoiesis. A theory of living organization*. New York: Elsevier North Holland.

Atlan, H. (1986) *À tort ou à raison. Intercritique de la science et du mythe*. Paris: Éditions du Seuil.

Atlan, H. (1995) Comment le dieu biblique peut « aller au hasard » en hébreu mais pas en traduction. *Meta: Journal Des Traducteurs*, 40, 3. pp. 508–5013

Atlan, H. (2011) *Selected Writings on Self-organization, Philosophy, Bioethics, and Judaism*. New York: Fordham University Press.

Attali, J. (1985) *Noise: The Political Economy of Music*. Minneapolis, Minnesota: University of Minnesota Press.

Axelrod, R. (1997) *The Complexity of Cooperation. Agent-Based Models of Competition and Collaboration*. Princeton, NJ: Princeton University Press.

Bach-y-Rita, P. and Kercel, S. (2003) Sensory substitution and the human-machine interface. *Trends Cogn Sci*, 7. pp. 541–546.

Bak, P., Tang, C. and Wiesenfeld, K. (1987) Self-organized criticality: an explanation of 1/ f noise. *Phys Rev Lett*,59. pp. 381–384

Baker, P. and Gourlet, T. (2015) *Data Divination: Big Data Strategies*. Boston, Massachusetts: Cengage Learning PTR.

Bateson, G. (2000) *Steps to an Ecology of Mind*. Chicago: University of Chicago Press.

Barbieri, F. (2008) Patterns of age-based linguistic variation in American English. *Journal of Sociolinguistics*, 12, 1. pp. 58–88.

Barkai, N. and Shilo, B. (2007) Variability and robustness in biomolecular systems. *Mol Cell*, 28, 5. pp. 755–760.

Batty, M., Morphet, R., Masucci, P. and Stanilov, K. (2014) Entropy, complexity, and spatial information. *J Geogr Syst* 16. pp. 363–385.

Bawa-Cavia, A. and Reed, P. (2020) Site as Procedure as Interaction. In: Beech, A. and Mackay, R. (Eds.) *Construction Site for Possible Worlds*. Falthmouth: Urbanomic.

Becskei, A. and Serrano, L. (2000) Engineering stability in gene networks by autoregulation. *Nature*, 405. pp. 590–593.

Bell, J.S. (1964) On the Einstein Podolsky Rosen paradox. *Physics* 1. pp. 195–200.

Bell, J.S. (1987) Are there Quantum Jumps? In Kilmister, W.M. (ed.), *Schrödinger: Centenary Celebration of a Polymath*. Cambridge: Cambridge University Press. pp. 105–110.

Ben-Naim, A. (2008) *A farewell to entropy: Statistical thermodynamics based on information*. Singapore: World Scientific.

Ben-Naim, A. (2009) An informational-theoretical formulation of the second law of thermodynamics. *Journal of Chemical Education*, 86, 1. pp. 99–105.

Ben-Naim, A. (2011) Entropy: Order or information. *Journal of Chemical Education*, 88, 5. pp. 594–596.

Berardi, F. (2017) *Futurability: The Age of Impotence and the Horizon of Possibility*. London: Verso.

Berger, J.O. (2006) *Statistical Decision Theory and Bayesian Analysis*. New York: Springer.

Bernoulli, J. (1713) *The Art of Conjecturing*. Part Four showing The Use and Application of the Previous Doctrine to Civil, Moral and Economic Affairs. Translated into English by Oscar Sheynin. Reprint. Berlin. 2005. Available from: http://www.sheynin.de/download/bernoulli.pdf [Accessed 15 April 2020]

Bianchi, E. (2014) *The Feminine Symptom: Aleatory Matter in the Aristotelian Cosmos*. New York: Fordham University Press.

Bijsterveld, K. (2008) *Mechanical Sound: Technology, Culture, and Public Problems of Noise in the Twentieth Century.* Cambridge, Mass.: MIT Press.

Blomberg, C. (2006) Fluctuations for good and bad: the role of noise in living systems. *Phys Life Rev*, 3. pp. 133–161.

Blum, H.F. (1968) *Time's arrow and evolution*. Princeton, NJ: Princeton University Press.

Bobadilla, J., Ortega, F., Hernando, A. and Gutiérrez, A. (2013) Recommender systems survey. *Knowledge-Based Systems*, 46. pp. 109-132.

Boin, A., 't Hart, P., Stern, E., and Sundelius, B. (2005) *The Politics of Crisis Management: Public Leadership under Pressure*. Cambridge: Cambridge University Press.

Boltzmann, L. (1966) Further Studies on the Thermal Equilibrium of Gas Molecules. In

Boltzmann, L. (1974) *Theoretical physics and philosophical problems*. New York: Springer-Verlag.

Borges, J.L. (1949) El Aleph, in *El Aleph*, Buenos Aires: Losada (Eng. trans. by A. Kerrigan, 'The Aleph', in a personal anthology, New York: Grove, 1967)

Born, M. (1971) *The Born-Einstein Letters.* London: Macmillan Press.

Bottéro, J. (1974) Sintomi, segni, scritture nell'antica Mesopotamia. In Vernant, J.P., Vandermeersch, L., Gernet, J., Bottéro, J., Crahay, R., Brisson, L., Carlier, J., Grodzynski, D. and Retel Laurentin, A. (Eds.) *Divination et Rationalité*, Paris: Seuil.

Bottéro, J. (1987) *Mésopotamie. L'écriture, la raison et les dieux*, Paris: Gallimard.

Boulton, J. (2011) Complexity Theory and Implications for Policy Development, *Emergence: Complexity and Organisation*. 12, 2. pp. 31-40.

Bowling Barnes, R. and Silverman, S. (1934) Brownian Motion as a Natural Limit to

All Measuring Processes. *Reviews of Modern Physics*. 6, pp. 162-193.

Bravi, B. and Longo, G. (2015) The unconventionality of nature: biology, from noise to functional randomness. Unconventional Computation & Natural Computation Conference (UCNC), Auckland (NZ) 31/8–4/9/2015. vol LNCS 9252, *Lecture Notes in Computer Science*. Springer. pp. 3–34

Bradley, J. (2016) Random Numbers and God's Nature, in Giberson, K.W. (ed.) *Abraham's Dice: Chance and Providence in the Monotheistic Traditions*. Oxford: Oxford University Press.

Brassier, R. (2009) nY, *Against an Aesthetics of Noise*. [online]. Available from: https://www.ny-web.be/artikels/against-aesthetics-noise/ [Accessed 30 May 2020]

Breiman, L. (2001) Statistical modeling: The two cultures. *Stat. Sci.* 16. pp. 199–231

Brenninkmeijer, J and Zwart, H. (2016) From 'hard' neuro-tools to 'soft' neuro-toys? Refocussing the neuroenhancement debate. *Neuroethics* 10. pp. 337–348.

Brier, S. (2010) Cybersemiotics: An Evolutionary World View Going Beyond Entropy and Information into the Question of Meaning. *Entropy*, 12. pp. 1902-1920.

Brillouin, L. (1962) *Science and information theory*. New York: Academic Press.

Brock, W. (1986) Distinguishing random and deterministic systems: Abridged version. *Journal of Economic Theory*, 40. pp. 168–195.

Brooks, D.R. and Wiley, E.O. (1986) *Evolution as Entropy: Toward a Unified Theory of Biology*. Chicago: University of Chicago Press.

Brooks, D. (2013). Opinion | The Philosophy of Data. *The New York Times*. [online] Available from: https://www.nytimes.com/2013/02/05/opinion/brooks-the-philosophy-of-data.html [Accessed 30 May 2020]

Brush, S.G. (ed.) *Kinetic Theory. Volume 2: Irreversible Processes.* London: Pergamon Press. pp. 88–175.

Burke, K. (2003) A Theory of Terminology. *On Human Nature, A Gathering While Everything Flows, 1967–1984*, edited by Burke, K., Rueckert, W. H. and Bonadonna, A. Berkeley, Los Angeles: University of California Press. pp. 229-246.

Byrne, E.F. (1968) Probability and Opinion: A Study of Medieval Presuppositions of Post-Medieval Theories of Probability. Dordrecht: Springer.

Calude, C. (2010). Information and Randomness: An Algorithmic Perspective, 2nd Edition, Revised and Extended. Berlin: Springer.

Calude, C. and Longo, G. (2016) Classical, quantum and biological randomness as relative unpredictability. *Nat Comput*. 15. pp. 263–278

Calude, C.S. (2017) Quantum Randomness: From Practice to Theory and Back. In: Cooper S., Soskova M. (Eds.) *The Incomputable. Theory and Applications of Computability* (In cooperation with the association Computability in Europe). Cham, Switzerland: Springer.

Camazine, S., Deneubourg, J-L., Franks, N., Sneyd, J., Theraulaz, G. and Bonabeau, E. (2002) *Self-Organization in Biological Systems*. Princeton, New Jersey: Princeton University Press.

Campbell, J. (1984) *Grammatical Man: Information, Entropy, Language and Life*. Harmondsworth: Penguin.

Canguilhem, G. (1963) The Role of Analogies and Models in Biological Discovery. In: Crombie, A.C. (Ed.), in *Scientific Change*. New York: Basic Books. pp. 507–520.

Canguilhem, G. (1994) *A Vital Rationalist, Selected Writings from Georges Canguilhem*. New York: Zone Books.

Carnap, R. (1929) *Der Logische Aufbau der Welt*. Leipzig: Felix Meiner Verlag.

Carnap, R. (1945) The Two Concepts of Probability, *Philosophy and Phenomenological*

Research, 5. pp. 513–32.

Carnot, S. (1824) *Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance*. Paris: Bachelier.

Carseti, A. (2013) *Epistemic Complexity and Knowledge Construction Morphogenesis, Symbolic Dynamics and Beyond*. Dordrecht: Springer.

Casti, J. (1991) *Paradigms Lost. Images of Man in the Mirror of Science*. New York: Morrow.

Casti, J. (1994) *Explaining a Paradoxical Worls through the Science of Surprise*. New York: Harper.

Cavaillés, J. (1940) Du Collectif Au Pari: A Propos De Quelques Théories Régentes Sur Les Probabilités. *Revue De Métaphysique Et De Morale*. 47 (2). pp. 139-163.

Ccru (2017) *Ccru: Writings 1997-2003*. Falmouth: Urbanomic.

Cetina, K.K. (1999) *Epistemic Cultures: How the Sciences Make* Knowledge. Cambridge, Mass.: Harvard University Press.

Chaitin, G. (1966) On the length of programs for computing finite binary sequences. *J ACM*, 13, 4. pp. 547–569.

Chaitin, G.J. (1975) Randomness and mathematical proof, Scientific American. 232 (5). pp. 47–52.

Chaitin G.J. (2001) *Exploring Randomness*, London: Springer.
Cooper, S.B. & Soskova, M.I. (Eds.), *The Incomputable. Journeys Beyond the Turing Barrier*. Berlin: Springer.

Chaitin, G. J. (2007) *Thinking About Gödel and Turing: Essays on Complexity, 1970-2007.* River Edge, NJ: World Scientific Publishing Co.

Chaitin, G. J. (2012) *Proving Darwin: Making Biology Mathematical*. New York: Pantheon.

Chaitin, G. J. / The University of Auckland (2019) *Centre for Discrete Mathematics and Theoretical Computer Science*. Available from: https://www.cs.auckland.ac.nz/research/groups/CDMTCS/docs/ait.php [Accessed 18 October 2019]

Chakraborty, S. (2010) On 'Why' and 'What' of Randomness, *DataCritica: International Journal of Critical Statistics*, Vol. 3. No. 2. pp. 1–13.

Châtelet, G. (2014) *To Live and Think Like Pigs*: *The Incitement of Envy and Boredom in Market Democracies.* Falmouth: Urbanomic.

Chemero, A. (2003) An outline of a theory of affordances. *Ecol Psychol,* 15, 2. pp. 181–195.

Chemero, A. (2011) *Radical embodied cognitive science*. Cambridge, MA: MIT Press.

Chomsky, N. (1957) Three Models for the Description of Language Offsite Link in IRE *Transactions on Information Theory* IT-2. pp. 113-124.

Chomsky, N. (1986) *Knowledge of Language: Its Nature, Origins, and Use*. Westport, CT: Convergence, Praeger.

Chopra, S. and Balakrishnan, S. (2010) Collaborative Ranking. In: *WSDM '12 Proceedings of the fifth ACM international conference on Web search and data mining*. Association for Computing Machinery. New York. pp. 143-152.

Clausius, R. (1867) *The Mechanical Theory of Heat – with its Applications to the Steam Engine and to Physical Properties of Bodies*. London: John van Voorst.

Ciechonska, M., Grob, A. and Isalan, M. (2016) From noise to synthetic nucleoli: can synthetic biology achieve new insights? *Integr Biol* 8, 4. pp. 383–393.

Clark, P. (1976). "Atomism versus thermodynamics". In Howson, Colin (ed.). *Method and appraisal in the physical sciences*. Cambridge University Press.

Clark, A. and Chalmers, D. (1998) The extended mind. *Analysis*, 58. pp. 7–19.

Clark, A. (2008) *Supersizing the mind: embodiment, action, and cognitive extension*. Oxford: Oxford University Press.

Clark, A. (2015) Radical predictive processing. *Southern Journal of Philosophy*, 53, S1. pp. 3–27.

Collier, J. (1986) Entropy in evolution. *Biology & Philosophy*, 1. pp. 5–24.

Collins, H. (1990) *Artificial Experts: Social Knowledge and Intelligent Machines*. Cambridge: Massachusetts University Press.

Combes, M. (2012) *Gilbert Simondon and the Philosophy of the Transindividual*. Cambridge, Massachusetts: MIT Press.

Crumley, C.L. (1987) A Dialectical Critique of Hierarchy. In: Patterson, T.C. and Gailey, C.W. (Eds.) *Power Relations and State Formation*. Washington, D.C.: Archeology Section/American Anthropological Association. pp. 155-69.

Crumley, C.L. (1995) Heterarchy and the analysis of complex societies, in: Ehrenreich, R.M., Crumley, C.L. and Levy, J.E. (Eds.) Heterarchy and the Analysis of Complex Societies. *Archeological papers* no. 6. Washington, DC: American Anthropological Association. pp. 1–6.

Crutchfield, J. (1994) The Calculi of Emergence. Computation, Dynamics, and Induction. *Physica D: Nonlinear Phenomena Volume*, 75, 1–3. pp. 11-54.

Crutchfield, J. (2002) Between order and chaos. *Nature Physics* 8. pp. 17–24.

Csernatoni, R. (2018) Constructing the EU's high-tech borders: FRONTEX and dual-use drones for border management. *European Security*, 27. pp. 175–200.

Czaplicka, A., Holyst, J. & Sloot, P. Noise enhances information transfer in hierarchical networks. *Sci Rep* 3, 1223.

Dalton, C.M., Taylor, L. and Thatcher, J. (2016) Critical data studies: A dialog on data and space. *Big Data & Society* 3, 1. pp. 1–9.

Darwin, C. (1859) *On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life*. London: John Murray.

De Moivre, A. (1756) *The doctrine of chances: or, a method for calculating the probabilities of events in play.* London: W. Pearson.

De Boever, A., Murray, A., Roffe, J. and Woodward, A. (eds.). (2012) *Gilbert Simondon: Being and Technology*. Edinburgh: Edinburgh University Press.

DeDeo, S. (2020) Mutual Explainability, or, a Comedy in Computerland. Available from: https://fqxi.org/data/essay-contest-files/DeDeo_Comedy_in_Computerlan.pdf [Accessed 15 April 2020]

Deibert, R.J. (2019) The Road to Digital Unfreedom: Three Painful Truths About Social Media. *Journal of Democracy*, 30, 1. pp. 25–39.

Deacon, T. (2012) Beyond the Symbolic Species. In: Schilhab, T., Stjernfelt, F. and Deacon, T. (Eds.) *The Symbolic Species Evolved*. Berlin: Springer Verlag. pp. 9–38.

Deleuze, G. (1990) *The Logic of Sense*. New York: Columbia University Press.

Deleuze, G. (2004) *Difference and Repetition*. London: Bloomsbury.

Deleuze, G. (2004b) *Desert Islands and Other Texts 1953–1974*. Trans. Michael Taormina. New York: Semiotext(e).

Deleuze, G. and Guattari, F. (2005) *A Thousand Plateaus: Capitalism and Schizophrenia*. Minneapolis: University of Minnesota Press.

Del Ferraro, G., Moreno, A., Min, B. et al. (2018) Finding influential nodes for integration in brain networks using optimal percolation theory. *Nature Communications*, 9, 2274.

Deneve, S.; Latham, P.E. and Pouget, A. (2001) Efficient computation and cue integration with noisy population codes. *Nat. Neurosci. 4*. pp. 826–831. Downey, R. And Hirschfeldt, D.R. (2010) *Algorithmic Randomness and Complexity*. New York: Springer.

Denning, P.J. (2007) Computing is a Natural Science. Communications of the ACM, 50, 7. pp. 13–18.

Deutsch, D. (1997) *The Fabric of Reality*. New York: Allan Lane.

Diels, H. and Kranz, W. (1951) *Die Fragmente Der Vorsokratiker*, 3 vols., 6th ed. Berlin: Wiedmann.

Ding, M., Chen, Y. and Kelso, J.A.S. (1997) Long term memory processes (1/f type) in human coordination. Phys Rev Lett, 79. pp. 4501–4504.

Dodig-Crnkovic, G. (2007) Where Do New Ideas Come From? How Do They Emerge? Epistemology as Computation (Information Processing). In: Calude, C. (Ed.) *Randomness and Complexity, from Leibniz to Chaitin*. Singapore: World Scientific. pp. 263–279.

Dorigo, M. (2005) Ant colony optimization theory: A survey. *Theoretical Computer Science*, 334. pp. 243-278.

Dotov, D.G., Nie, L. and Chemero, A. (2010) A demonstration of the transition from ready-to-hand to unready-to-hand. *PLoS One*, 5, 3:e9433.

Dotov, D., Nie, L., Wojcik, K., Jinks, A., Yu, X. and Chemero, A. (2017) Cognitive and movement measures reflect the transition to presence-at-hand. *New Ideas Psychol,* 45. pp. 1–10.

Dyson, F. (1988) *Infinite In All Directions*. New York: Harper & Row.

Eagle, A. (2005) Randomness is unpredictability. *British Journal for the Philosophy of Science* 56 (4). pp. 749–790.

Eberhard, v.G., Paul, J. and Newbury, J. (2003) Heterarchy-Hierarchy: Two complementary categories of description. *Vordenker: Webforum for Innovative Approaches in Sciences, Economy and Culture*. [online] Available from: http://www.vordenker.de/heterarchy/a_heterarchy-e.pdf [Accessed 18 April 2020]

Ebrahimi, N.; Soofi, E.S. and Soyer, R. (2010) Information measures in perspective. *Int. Stat. Rev.* 78. pp. 383–412.

Economist, The (2017) The world’s most valuable resource is no longer oil, but data. *The Economist,* 6 May 2017. [online] Available from: https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data [Accessed 18 April 2020]

Einstein, A. (1949) Autobiographical Notes, in: P. A. Schilpp (ed.), *Albert Einstein: Philosopher-Scientist*. New York: Library of Living Philosophers.

Eldar, A. and Elowitz, M. (2010) Functional roles for noise in genetic circuits. *Nature*, 467. pp. 167–173.

Elgin, C.Z. (1997) *Between the Absolute and the Arbitrary*. Ithaca: Cornell University Press.

Elowitz, B. and Leibler, S. (2000) A synthetic oscillatory network of transcriptional translation. *Nature,* 403, 6767. pp. 335–338.

Elowitz, B., Levine, A., Siggia, E. and Swain, P. (2002) Stochastic gene expression in a single cell. *Science*, 297. pp. 1183–1186.

Emmeche, C. and Kalevi, K. (2011) *Towards a Semiotic Biology: Life Is the Action of Signs*. London: Imperial College Press.

Espinoza, M. (1995). Rene Thom: De la Teoria de Catastrofes a la Metafisica. *Themata*, 14. pp. 321–348.

Esposito, E. (2013) Digital prophecies and web intelligence. In: Hildebrandt, H. and de Vries, K. (Eds) *Privacy, Due Process and the Computational Turn: The Philosophy of Law Meets the Philosophy of Technology.* London: Routledge.

European Commission (2017) Responsible research and innovation. Horizon2020. [online] Available from: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation. [Accessed 18 April 2020]

Falk, R. and Konold, C. (1997) Making sense of randomness: Implicit encoding as a basis for judgment. *Psychol. Rev.* 104. pp. 301–318.

Fasoli M and Carrara, M. (2014) Artefatti cognitivi sostitutivi, innovativi e complementari. Proceedings of AISC 2014, Corpi, strumenti e cognizione. pp 144–149

Fasoli, M. (2016) Neuroethics of cognitive artifacts. In: Lavazza, A. (Ed.) *Frontiers in Neuroethics*. Newcastle: Cambridge Scholars Press. pp 67–82.

Favereau, D. (2010) *Essential Readings in Biosemiotics: Anthology and Commentary*. Dordrecht: Springer Verlag.

Felin, T., Kauffman, S., Koppl, R. and Longo, G. (2014) Economic Opportunity and Evolution: Beyond Landscapes and Bounded Rationality. *Strategic Entrepreneurship Journal*, Vol. 8, issue 4. pp. 269–282.

Feynman, R.P. (1982) Simulating physics with computers. International Journal of Theoretical Physics 21, 6. pp. 467–488.

Finetti, B.D. (1975) Theory of Probability. A Critical Introductory Treatment. Chichester: Wiley.

Fiorini, R. A. (2014) The entropy conundrum: A solution proposal. 1st International Electronic Conference on Entropy and Its Applications. 3-21 November 2014. Available from: www.sciforum.net/conference/ecea-1 [Accessed 15 April 2020]

Floridi, L. (2008) *Against digital ontology*. Synthese, 168, 1. pp. 151–178.

Floridi, L. and Sanders, J. (2013) Distributed morality in an information society. *Sci Eng Ethics*, 19, 3. pp.727–743.

Ford, I. (2013) *Statistical physics: An entropic approach*. Chichester, UK: Wiley.

Ford, K. M. and Pylyshyn, Z.W. (Eds) (1996) *The robot's dilemma revisited: The frame problem in artificial intelligence*. Norwood, NJ: Ablex.

Foucault, M. (1986) Of Other Spaces. *Diacritics*. 16 (1). pp. 22-27.

Fredkin, E. (1990) Digital Mechanics. *Physica D*, 45. pp. 254-270.

Fredkin, E. (2003) An Introduction to Digital Philosophy. *International Journal of Theoretical Physics*, 42, 2. pp. 189–247.

Freudenthal, H. (1968). Realistic models in probability, in Lakatos I. (ed.), *Problems in inductive logic, Proceedings of the International Colloquium in the Philosophy of Science, London, 1965, volume 2*. Amsterdam: North-Holland. pp. 1-14

Fulda, A. (2017) *Emmanuel Macron: Un jeune homme si*. Paris: Plon.

Galilei, G. (1957). *Discoveries and Opinions of Galileo*. Trans. S. Drake. Garden City, N.Y.:
Doubleday.

Galton, F. (1889) *Natural Inheritance*. London: Macmillan.

Garber, M (2013) How Google's Autocomplete Was ... Created / Invented / Born. *The Atlantic* [online]. Available from: https://www.theatlantic.com/technology/archive/2013/08/how- googles-autocomplete-was-created-invented-born/278991/ [Accessed 16 June 2020]

Garnier, S., Gautrais, J. and Theraulaz, G. (2007) The biological principles of swarm intelligence. *Swarm Intelligence*, I. pp. 3-31.

Garcia-Bernardo, J. and Dunlop, M.J. (2013) Tunable stochastic pulsing in the Escherichia coli multiple antibiotic resistance network from interlinked positive and negative feedback loops. *PLoS Comput Biol*, 9, 9. e1003229.

Gaspard, P. and Wang, X.-J. (1993) Noise, chaos, and (ε, τ)-entropy per unit time. *Physics Reports*, 235, 6. pp. 291–343.

Gatlin, L. (1972) *Information and the living system*. New York: Columbia University Press.

Ge, M., Delgado, C. and Jannach, D. (2010) Beyond accuracy: Evaluating recommender systems by coverage and serendipity. *RecSys'10 - Proceedings of the 4th ACM Conference on Recommender Systems*. pp. 257-260.

Gell-Mann, M. (1995) What is complexity? *Complexity*, 1,1. pp. 16-19.

Gell-Mann, M. (1996) Let's Call It Plectics. *Complexity*, 1, 5. p. 3.

Gell-Mann, M. and Lloyd, S. (1996) Information measures, effective complexity and total information. Complexity, 2, 1. pp. 44-52.

Geyer, R. and Samir, R. (2010) *Complexity and Public Policy. A New Approach to 21st Century Politics, Policy, and Society*. London: Routledge.

Ghirardi, G.C.; Rimini, A. and Weber, T. (1986) Unified Dynamics for Microscopic and Macroscopic Systems. *Physical Review D*, vol. 34. p. 470.

Gibbs, J.W. (1928) *The Collected Works of J. Willard Gibbs.* New York: Longmans, Green.

Giere, R.N. (1973) Objective Single-Case Probabilities and the Foundations of Statistics. In Suppes, P.; Henkin, L.; Joja, A. and Moisil G.C. (eds.) *Logic, methodology and philosophy of science IV.* Amsterdam: North-Holland. pp. 467–483.

Gillespie, T., Boczkowski, P.J. and Foot, K.A. (2014) *Media technologies: essays on communication, materiality, and society.* Cambridge, MA: MIT Press.

Gitelman, L. (Ed.) (2013) *'Raw Data' is an Oxymoron*. Cambridge, MA: MIT Press.

Gitterman, M. (2008) *The noisy pendulum*. New Jersey: World Scientific.

Glass, L. and Mackey, M.C. (1988) *From clocks to chaos: The rhythms of life*. Princeton: Princeton University Press.

Gleick, J. (1987) *Chaos Making a New Science*. New York: Penguin Books.

Goddard, M., Halligan, B., and Hegarty, P. (Eds.) (2012) *Reverberations: The Philosophy, Aesthetics and Politics of Noise*. London: Continuum.

Goldenfeld N (2018) Interviewed by for Science Daily, 21 June. [online] Available from: https://www.sciencedaily.com/releases/2018/06/180621121857.htm [Accessed 18 April 2020]

Goodman, N. (1972) *Problems and Projects*. Indianapolis and New York: Bobbs-Merrill.

Goodman, N. (1978) *Ways of Worldmaking*. Indianapolis: Hackett.

Goodman, N. (1983) *Fact, Fiction and Forecast*. Cambridge: Harvard University Press.

Goodman, N. (1984) *Of Mind and Other Matters*. Cambridge: Harvard University Press.

Gould, S.J. (2000) *Wonderful Life: the Burgess Shale and the Nature of History*. New York: Random House.

Graham, W.D. (2010) *The Texts of Early Greek Philosophy. The Complete Fragments and Selected Testimonies of the Major Presocratics*. Part 1. Cambridge: Cambridge University Press.

Grant, I.H. (2006) *Philosophies of Nature after Schelling*. London: Continuum.

Grant, I.H. (2007) The Insufficiency of Ground: On Žižek's Schellingianism. In: Bowman, P., ed., and Stamp, R., eds., (2007) *The Truth of ŽIžek*. London: Continuum. pp. 82-98.

Grant, I.H. (2015) Everything is primal germ or nothing is: The deep field logic of nature *Symposium: Canadian Journal of Continental Philosophy*, 19, 1. pp. 106–124.

Grant, I.H. (2020) *Goodman on the Fact of the Fabrication of Fact* [lecture of Metaphysics], UWE Bristol. 20 March.

Grobstein, C. (1973) Hierarchical order and neogenesis, in: Pattee. H.H. (Ed.) *Hierarchy theory*. New York: George Braziller.

Grove, J.V. (2019) *Savage Ecology: War and Geopolitics at the End of the World*. Durham, North Carolina: Duke University Press.

Hacking, I. (2006) *The Taming of Chance and The Emergence of Probability: A Philosophical Study of Early Ideas About Probability, Induction, and Statistical Inference.* Cambridge: Cambridge University Press.

Hadot, P. (2004) *Le voile d'Isis. Essai sur l'histoire de l'idée de nature*. Paris: Éditions Gallimard.

Hainge, G. (2013) *Noise Matters – Towards an Ontology of Noise*. London: Bloomsbury.

Hájek, A. (2009) Fifteen Arguments Against Hypothetical Frequentism, *Erkenntnis*, 70. pp. 211–35.

Handel, P.H. and Chung, A.L. (1993) *Noise in physical systems and 1/"f" fluctuations*. New York: American Institute of Physics.

Harrison, N.E. (ed.) (2006) *Complexity in World Politics. Concepts and Methods of a New Paradigm*. New York: State University of New York Press (Suny Series in Global Politics).

Hayles, N.K. (1990) *Chaos bound: Orderly disorder in contemporary literature and science*. Ithaca, NY: Cornell University Press

Hayes, B. (2008) *Group Theory in the Bedroom, and Other Mathematical Diversions*. New York: Hill and Wang.

Heartney, E. (2004) Defending Complexity: Art, Politics, and the New World Order. Stockbridge: Hard Press Editions.

Heims, S, J. (1980) *John Von Neumann and Norbert Wiener, From Mathematics to the Technologies of Life and Death*. Cambridge, MA: MIT Press.

Heersmink R (2013) A taxonomy of cognitive artifacts: function, information, and categories. *Rev Philos Psychol*, 4. pp. 465–481

Heersmink, R. (2014) Dimensions of integration in embedded and extended cognitive systems. *Phenomenol Cogn Sci.* 14, 3. pp. 577–598

Heersmink R (2016) The metaphysics of cognitive artifacts. *Philos Explor*, 19. pp. 78–93.

Heersmink, R. (2017) Distributed cognition and distributed morality: agency; artifacts and systems. *Sci Eng Ethics*, 23. pp. 431–448

Heersmink R (2017) Extended mind and cognitive enhancement: moral aspects of cognitive artifacts. *Phenomenol Cogn Sci,* 16. pp. 17–32.

Hegarty, P. (2007) *Noise/Music – A History*. New York: Continuum.

Heidegger, M. (1927/1962) *Being and time*. New York: Harper & Row Publishers.

Heylighen, F. (1997) Self-organization, Principia Cybernetica Website. [online] Available from: http://pespmc1.vub.ac.be/SELFORG.html [Accessed 18 April 2020]

Hockey, Th. et al. (2014) *Biographical Encyclopedia of Astronomers*. New York: Springer-Verlag.

Hoefer, C. (2007) The Third Way on Objective Probability: A Skeptic's Guide to Objective Chance, *Mind*, 116 (2). pp. 549–596.

Hofstadter, D. (1979) *Gödel, Escher, Bach: An Eternal Golden Braid*. New York: Basic books.

Holden, J.G., Van Orden, G.C. and Turvey, M.T. (2009) Dispersion of response times reveals cognitive dynamics. *Psychol Rev*, 116. pp. 318–342.

Holland, J. (1996) *Hidden Order: How Adaptation Builds Complexity*. New York: Basic Books.

Holland, J. (1998) *Emergence, From Chaos to Order.* Reading, MA: Addison-Wesley.

Hui, Y. (2019) *Recursivity and Contingency*. Lanham, Maryland: Rowman & Littlefield International.

Hume, D. (1888). *Hume's Treatise of Human Nature.* Selby-Bigge, L.A. (ed.). Oxford: Clarendon Press.

Hume, D. (1978) *A Treatise of Human Nature*, 2 edn. Oxford: Oxford University Press.

Huynh, D.T. (1992) Non-uniform complexity and the randomness of certain complete languages. *Theor. Comput. Sci*., 96. pp. 305–324.

Hurley, S. and Noë, A. (2003) Neural plasticity and consciousness. *Biol Philos*, 18. pp. 131–168.

Ihlen, E.A.F. and Vereijken, B. (2010) Interaction-dominant dynamics in human cognition: beyond 1/fα fluctuations. *J Exp Psychol Gen,* 139. pp. 436–463

Jeffrey, R. (1992) *Probability and the Art of Judgment*. Cambridge, MA: Cambridge University Press.

Jensen, H.J. (1998) *Self-organized criticality*. Cambridge: Cambridge University Press.

Jervis, R. (1998) *System Effects: Complexity in Politics and Social Life*. Princeton: Princeton University Press.

Johns Hopkins University (2014) The Johns Hopkins Foreign Affairs Symposium Presents: The Price of Privacy: Re-Evaluating the NSA. [online video]. Available at: https://www.youtube.com/watch?v=kV2HDM86XgI [Accesed: 16 July 2020]

Juarrero, A. (1999) *Dynamics in Action: Intentional Behavior as a Complex System*. Cambridge, MA: MIT Press.

Jung, C.G. (1952) Synchronizität als ein Prinzip akausaler Zusammenhänge. In Jung, C.G. (1971) *Gesammelte Werke*, Band 8. Olten: Walter-Verlag. pp. 457-554.

Kaehr, R. (2003) Derrida's Machine. [online]. Available from: http://www.thinkartlab.com/pkl/media/index.htm [Accessed 18 April 2020]

Kallenberg, O. (2002) *Foundations of Modern Probability*. New York, NY: Springer.

Kampis, G. and Weibel, P. (Eds.) (1993) *Endophysics. A New Approach to the Observer Problem with Applications in Physics, Biology and Mathematics*. Santa Cruz, CA: Aerial Press.

Kant, I. (1993) *Opus postumum*, tr. Eckart Förster. Cambridge: Cambridge University Press.

Karig, D., Martini, K., Lu, T., DeLateur, N., Goldenfeld, N. and Weiss, R. (2018) Stochastic Turing patterns in a synthetic bacterial population. *Proc Natl Acad Sci*, 115, 26. pp. 6572–6577.

Kauffman, S. (1995) *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity*. Oxford: Oxford University Press.

Kauffman, S. (1996) Investigations: The nature of autonomous agents and the worlds they mutually create. SFI working paper # 96-08-072. Santa Fe Institute.

Kauffman, S. (2000) *Investigations*. Oxford: Oxford University Press.

Kauffman, S., Logan, R.K., Este, R., Goebel, R., Hobill, D. and Shmulevich, I. (2008) Propagating organization: an enquiry. *Biol Philos*, 23. pp. 27–45.

Kay, B.A. (1988) The dimensionality of movement trajectories and the degrees of freedom problem: a tutorial. *Hum Mov Sci,* 7. pp. 343–364.

Keizer, J. (1987) *Statistical thermodynamics of nonequilibrium processes*. Berlin: Springer.

Kello, C.T., Beltz, B.C., Holden, J.G. and Van Orden, G.C. (2007) The emergent coordination of cognitive function. *J Exp Psychol Gen,* 136. pp. 551–568.

Kelly, C. (2009) *Cracked Media: The Sound of Malfunction*. Cambridge, MA: MIT Press

Kelso, J.A.S. (1995) *Dynamic patterns: the self-organization of brain and behavior*. Cambridge, MA: MIT Press.

Keynes, J. M. (1921). *A Treatise on Probability*. London: Macmillan.

Keynes, J.M. (1923). *A tract on monetary reform*. London: MacMillan and Co.

King, I.T. (2000) *Social Science and Complexity: The Scientific Foundations*. Huntington, NY: Nova Science Publishers.

Kitchin, R. (2017) Thinking critically about and researching algorithms. *Inf Commun Soc*, 20, 1. pp. 14–29.

Klagenfurt, K. (2001) *Technologische Zivilisation und transklassische Logik. Eine Einfuhrung in die Technikphilosophie Gotthard Gunthers*. Frankfurt: Suhrkamp.

Kloppenburg, S. and Van der Ploeg, I (2020) Securing identities: biometric technologies and the enactment of human bodily differences. *Science as Culture*, 29, 1. pp. 57–76.

Knott, C.G. (1911) *Life and Scientific Work of Peter Guthrie Tait Supplementing the Two Volumes of Scientific Papers Published in 1898 and 1900*. Cambridge: Cambridge University Press.

Knuuttila, T. and Loettgers, A. (2011) Synthetic modeling and the functional role of noise, paper presented at epistemology of modeling and simulation:building research bridges between the philosophical and modeling communities, University Club, University of Pittsburgh, 1–3 April 2011.

Knuuttila, T. and Loettgers, A. (2014) Varieties of noise: analogical reasoning in synthetic biology. *Stud Hist Phil Sci,* 48. pp. 76–88.

Kobsa, A., Nierstrasz, O., Weikum, G. (Eds) (2011) *Transactions on Large-Scale Data- and Knowledge-Centered Systems*. Berlin: Springer.

Kojima Productions (2019) *Death Stranding*. [Video game]. Sony Interactive Entertainment.

Kolmogorov, A.N. (1933) *Grundbegriffe de Wahrscheinlichkeitsrechnung*. Berlin: Springer.

Kolmogorov, A.N. (1965) Three approaches to the quantitative definition of information. Problems of Information Transmission. *International Journal of Computer Mathematics*, 2, 1-4. pp. 157-168.

Kolmogorov, A.N. (1983) Combinatorial foundations of information theory and the calculus of probabilities. *Russ Math Surv*, 38, 4. pp. 27–36.

Kolmogorov, A.N. and Uspenskii, V.A. (1987) Algorithms and randomness. *Theory of Probability & Its Applications*, 32. pp. 389-412.

Konstan, D. (1979) Problems in Epicurean Physics. *Isis: A Journal of the History of Science*. 70 (3). pp. 394-418.

Kraak, S. (2018) *Post-truth in the age of the algorithm*. MA thesis, Maastricht University.

Krapp, P. (2011) *Noise Channels: Glitch and Error in Digital Culture*. Minneapolis, Minnesota: University of Minnesota Press

Krauss, L. and Scherrer, R. (2008) The End of Cosmology?. *Scientific American*. 298.pp 46–53.

Landsman, K. (2019) Randomness? What Randomness?, *Foundations of Physics*, 50. pp. 61–104.

Kussell, E., Kishony, R., Balaban, N. and Leibler, S. (2005) Bacterial persistence: a model of survival in changing environments. *Genetics,* 169. pp. 1807–1814.

Land, N. (2011) *Fanged Noumena: Collected Writings 1987 - 2007*. Falmouth: Urbanomic.

Langer, S.K. (1967). *Mind: An Essay on Human Feeling*, vol. 1. Baltimore, MD: Johns Hopkins University Press.

Langer, S.K. (1972). *Mind*, vol. 2. Baltimore, MD: Johns Hopkins University Press.

Langer, S.K. (1982). *Mind*, vol. 3. Baltimore, MD: Johns Hopkins University Press.

Langton, C.G. (1990) Computation at the edge of chaos: Phase transition and emergent computation. *Physica D*, 42. pp. 12–37.

Laplace, P.-S. (1814) *Essai philosophique sur les probabilités*. Paris: Bourgois.

Larson, J., Mattu, S., Kirchner, L. and Angwin, J. (2016) How We Analyzed the COMPAS Recidivism Algorithm. ProPublica 23 May 2016. [online] Available from: https://www.propublica.org/article/how-we-analyzed-the-compas-recidivism-algoritm [Accessed 18 April 2020]

Lazer, D., Kennedy, R., King, G. and Vespignani, A. (2014) The Parable of Google Flu:

Traps in Big Data Analysis. *Science*, 343, 6176. pp. 1203–1205.

Leander, A. and Wæver, O. (Eds.) (2019) *Assembling Exclusive Expertise: Knowledge, Ignorance and Conflict Resolution in the Global South. Worlding Beyond the West.* Abingdon: Routledge.

Lear, J. (2003) *Something for Nothing: Luck in America*. New York: Viking Books.

Lee, J.A.N. (1995) *Computer Pioneers*. Los Alamitos, CA: IEEE Computer Society Press.

Leibniz, G.W. (1875–90) Die philosophischen Schriften. 7 vols. Edited by C. I. Gerhardt. Berlin, Reprint, Hildesheim: Georg Olms, 1965. Cited by volume and page number.

Lestas, I., Vinnicombe, G. and Paulsson, J. (2010) Fundamental limits on the suppression of molecular fluctuations. *Nature*, 467. pp. 174–178.

Levine, J. (1983) Materialism and qualia: the explanatory gap. *Pacific Philosophical Quarterly*, 64. pp. 354-361.

Lewis, G.N. (1930) The symmetry of time in physics, *Science*, 71. pp. 569-577

Lewis, D. (1973). *Counterfactuals*. Cambridge: Harvard University Press.

Lewis, D. (1980) A Subjectivist's Guide to Objective Chance, in Jeffrey, C.R. (ed.), *Studies in Inductive Logic and Probability, vol. II.* Berkeley: University of California Press.

Lewis, D. (1987) *Philosophical Papers: Volume II*. Oxford: Oxford University Press.

Lewis, D. (1994) Supervenience debugged. *Mind*, 103. pp. 473–490.

Lewis-Kraus, G. (2014) The Fasinatng ... Frustrating ... Fascinating History of Autocorrect. *Wired | Gadget Lab* [online]. Available from: http://www.wired.com/2014/07/history- of-autocorrect/ [Accessed 16 June 2020]

Lewontin, R. (2000) *The triple helix: gene, organism, and environment*. Cambridge, MA: Harvard University Press.

Li, M. and Vitanyi, P. (1997) *An introduction to Kolmogorov complexity and its applications*. London: Springer Verlag.

Liu, J. (2008) At a Loss for Words? *Official Google Blog* [online]. Available from: http:// googleblog.blogspot.com/2008/08/at-loss-for-words.html [Accessed 16 June 2020]

Lloyd, S. and Pagels, H. (1988) Complexity as thermodynamic depth. *Annals of physics*, 188, 1. pp. 186-213.

Lloyd, S. (2010) Computational universe. In: Davies, P.C.W. and Gregersen, N.H. (Eds.), *Information and the Nature of Reality: From Physics to Metaphysics*. Cambridge, MA: Cambridge University Press.

Llull, R. (2003) *Ars Generalis Ultima* [online]. Available from: http://lullianarts. narpan.net/Ars-Magna/1-2-3-4.htm [Accessed 16 June 2020]

Loettgers, A. (2009) Synthetic biology and the emergence of a dual meaning of noise. *Biol Theory,* 4, 4. pp. 340–356.

Loewer, B. (2001) Determinism and Chance, *Studies in History and Philosophy of Modern Physics*, 32. pp. 609–20.

London, M.; Roth, A.; Beergen, L.; Hausser, M. And Latham, P.E. (2010) Sensitivity to perturbations in vivo imply high noise and suggests rate coding in cortex. *Nature*. *466*, pp. 123–127.

Longo, G. (2009) Laplace, Turing and the "Imitation Game" Impossible Geometry. In Epstein, R., Robert, G. and Beber G. (eds.), *Parsing the Turing Test. Philosophical and Methodological Issues in the Quest for the Thinking Computer*. Dordrecht, Netherlands: Springer.

Longo, G. (2010) Randomness, Determinism and Programs in Turing's Test. In Carsetti, A., (Ed.), *Causality, Meaningful Complexity and Embodied Cognition*. London: Springer.

Longo, G. (2017) How future depends on past histories and rare events in systems of life. *Found Sci*. pp. 1–32.

Longo G. (2020) Information, Science and Democracy, for an Ethics of Scientific Knowledge. In: Fabris, A. (Eds) *Trust. Trust 2020*. Studies in Applied Philosophy, Epistemology and Rational Ethics, vol 54. Cham: Springer. pp. 63–79.

Lopes, L.L. and Oden, G.C. (1987) Distinguishing Between Random and Nonrandom Events. *Journal of Experimental Psychology*: *Learning, Memory, and Cognition*, 13. pp. 392-400.

Lorenz, E.N. (1963) Deterministic Nonperiodic *Flow. J. Atmos. Sci*. 20. pp. 130–141.

Lotman, J. (2005) On the semiosphere. *Sign Systems Studies*, 33, 1. pp. 205–229.

Lotman, J. (2009) *Culture and explosion*. Berlin: De Gruyter Mouton.

Lovejoy, A.O. (1936) *The Great Chain of Being*. New York: Harper & Row.

Lucas, R. (2020) The Surveillance Business. New Left Review. 121. pp. 132–141.

Lucretius (1976) *De Rerum Natura: The Poem on Nature*. Manchester: Carcanet Press.

Luhmann, N. (1996) *Die Kontrolle von Intransparenz*, unpublished manuscript, Bielefeld.

Luhmann, N. (1997) *Die Gesellschaft der Gesellschaft*, Frankfurt: Suhrkamp.

Luhmann, N. (2000) *Organisation und Entscheidung*. Opladen: Westdeutscher Verlag.

Lyotard, J.F. (1984) *The Postmodern Condition A Report on Knowledge*. Minneapolis: University of Minnesota Press.

MacKay, D. (1969) *Information, mechanism and meaning*. Cambridge, MA: MIT Press.

Mackenzie, A. (2002) *Transductions: Bodies and Machines at Speed*. London: Continuum.

Mackenzie, A. (2015) The production of prediction: What does machine learning want? *European Journal of Cultural Studies*. 18, 4–5. pp. 429–445.

Mackenzie, A. (2018) *Machine Learners: Archaeology of a Data Practice*. Cambridge: Massachusetts University Press.

MacKenzie, D. (2006) *An Engine, Not a Camera. How financial models shape markets*. Cambridge, Mass.: MIT Press.

Maclaurin, J. (1998) Reinventing molecular Weissmanism. *Biol Philos,* 13, 1. pp. 37–59.

Maidenbaum, S., Abboud, S. and Amedi, A. (2014) Sensory substitution: closing the gap between basic research and widespread practical visual rehabilitation. *Neurosci Biobehav Rev*, 41. pp. 3–15.

Malaspina, C. (2018) *An Epistemology of Noise*. London: Bloomsbury.

Maldonado, C.E. (2013) Consecuencias políticas de la complejidad. *Iztapalapa Revista de Ciencias sociales y Humanidades*, 74. pp. 189-208.

Mandelbrot, B.B. (1997) *Fractals and Scaling in Finance*. New York: Springer-Verlag.

Marx, K. (1993) *Grundrisse: foundations of the critique of political economy* (rough draft). London: Penguin/New Left Review.

Marx, K. (2000) *Selected Writings*. David McLellan (Ed.), 2nd edition. Oxford: Oxford University Press.

Marx, K. (2000b) *Capital: Volume I* in Marx 2000. pp. 452-525.

Mattin and Iles, A. (Eds.) (2009) Noise & Capitalism. Loiola, Gipuzkoa: Arteleku.

Mattin (2017) *Social Dissonance*. PhD, Universidad del País Vasco, international PhD thesis in Collaboration with: American University of Beirut

Maudlin, T. (1997) Descrying the World in the Wave Function. *The Monist*, Vol. 80, No. 1. pp. 3–23.

Mauss, M. (1972) *A General Theory of Magic*. Abingdon: Routledge and Kegan Paul.

Maynard Smith, J. (2000) The concept of information in biology. *Philos Sci*, 67, 2. pp. 177–194.

McCulloch, W. (1945) A Heterarchy of Values Determined by the Topology of Nervous

Nets. *Bulletin of Mathematical Biophysics*. 7.2. pp. 89–93.

McFedries, P. (2017) Data Divination. *IEEE Spectrum*, Vol. 54, No. 2. p. 25.

Meacham D (2017) Critiquing technologies of the mind: enhancement, alteration, and anthropotechnology (Introduction). *Phenomenol Cogn Sci.* 16, 1. pp. 1–16.

Mehta, P.K., Bess, C., Elias-Smale, S., Vaccarino, V., Quyyumi, A., Pepine, C.j. and Bariey Merz, C.N. (2019) Gender in cardiovascular medicine: chest pain and coronary artery disease. *European Heart Journal*. 40, 47. pp. 3819–3826.

Meillassoux, Quentin (2008) *After Finitude: An Essay on the Necessity of Contingency*. New York: Continuum.

Menary, R. (Ed.) (2010) *The extended mind*. Cambridge, MA: MIT Press.

Menary, R. (2010) Introduction to the special issue on 4E cognition. *Phenomenol Cogn Sci,* 9. pp. 459–463

Merleau-Ponty, M. (1945/1962) *Phenomenology of perception*. London: Routledge & Kegan Paul.

Merleau-Ponty, M. (1964) *The Primacy of Perception*. Evanston: Northwestern University Press.

Meyer, H. and Roeder, A. (2014) Stochasticity in plant cellular growth and patterning. *Front Plant Sci*, 5. 420.

Milano, S., Taddeo, M. and Floridi, L. (2020) Recommender systems and their ethical challenges. *AI & Soc*.

Mitchell, M. (2009) *Complexity: a guided tour*. New York: Oxford University Press.

Mohr, R.D. (2005) *God and Forms in Plato*. Las Vegas: Parmenides.

Monod, J. (1971) *Chance and necessity: an essay on the natural philosophy of modern biology*. New York: Vintage Books.

Moore, J.W. (2015) *Capitalism in the Web of Life: Ecology and the Accumulation of Capital*. London: Verso Books.

Moore, O.K. (1957) Divination: a new perspective. American Anthropologist, 59. pp. 69–74.

Morgan, S. (2018) Fake news, disinformation, manipulation and online tactics to undermine democracy. Journal of Cyber Policy, 3, 1. pp. 39–43.

Morin, E. (1973) *Le Paradigme perdu*: *la nature humaine*. Paris: Éditions du Seuil.

Morin, E. (1992) *Method: Towards a Study of Mankind: Vol. 1, The Nature of Nature*. New York: Peter Lang.

Mumford, S. (2006) The Ungrounded Argument. *Synthese* 149. pp. 471-489.

Murray, M.M., Thelen, A., Thut, G., Romei,V., Martuzzi, R. and Matusz, P.J. (2016) The multisensory function of the human primary visual cortex. *Neuropsychologia*, 83. pp. 161–169.

National Science Foundation (2010) *Computational and Data-Enabled Science and* Engineering. Available from: http://www.nsf.gov/mps/cds-e/ [Accessed 16 June 2020]

Negarestani, R. (2018) *Intelligence and Spirit*. Falthmouth: Urbanomic.

Nechvatal, J. (2011) *Immersion Into Noise*. London: Open Humanities Press.

Neyman, J. and Pearson, E.S. (1928) On the use and interpretation of certain test criteria for purposes of statistical inference: Part i. *Biometrika* 20A. pp. 175–240.

Neyman, J. and Pearson, E.S. (1933) On the problem of the most efficient tests of statistical hypotheses. *Philos. Trans. R. Soc. Lond. Ser. A* 231. pp. 289–337.

Nicolis, G. and Nicolis, C. (2007) *Foundations of Complex Systems: Nonlinear Dynamics, Stathistical Physics, information and Prediction*. Singapore: World Scientific.

Nicolis, G. and Prigogine, I. (1977) Self-Organization in Nonequilibrium Systems. From Dissipative Structures to Order through fluctuations. *Berichte Der Bunsengesellschaft*

Für Physikalische Chemie, 82, 6. pp. 672–672.

Nietzsche, F. (1976) *Nietzsche Werke. Kritische Gesamtausgabe*, ed. by G. Colli and M. Montinari, ca. 30 Vols, in eight divisions. Berlin: Walter de Gruyter.

Noë, A. (2015) Strange Tools: Art and Human Nature. New York: Hill and Wang.

Norman, D. (1991) Cognitive artifacts. In: Carroll, J.M. (Ed.) *Designing interaction: psychology at the human-computer interface*. Cambridge: Cambridge University Press. pp. 17–38.

North, M. and Macal, C. (2007) *Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation*. Oxford: Oxford University Press.

Nunes, M (Ed.) (2010) *Error: Glitch, Noise, and Jam in New Media Cultures*. New York: Bloomsbury.

Oppenheim, P. and Putnam, H. (1958) Unity of Science as a Working Hypothesis. In: Feigl, H., Scriven, M and Maxwell, G. (Eds.) *Concepts, Theories, and the Mind-Body Problem*. Minneapolis: University of Minnesota Press.

Ozbudak, E., Thattai, M., Kurtser, I., Grossman, A. and van Oudenaarden, A. (2002) Regulation of noise in the expression of a single gene. *Nat Genet*, 31. pp. 69–73.

Paley, W. (1881) *Natural Theology*. New York: American Tract Society.

Pattee, H. (1973) The physical basis and origin of hierarchical control. Pattee. H.H. (Ed.) *Hierarchy theory*. New York: George Braziller.

Peirce, C.S. (1931–1935, & 1958). The collected papers of Charles Sanders Peirce. Vols. I–VI, Hartshorne C. and Weiss P., (Eds.), (1931–1935), Vols. VII–VIII (Burks, A.W. (ed.), (1958). Cambridge, MA: Harvard University Press. (Citations use the common form: CP vol. paragraph).

Peirce, C.S. (1935) *Collected Papers of Charles Sanders Peirce, vol. VI: Scientific* Metaphysics. Cambridge: Cambridge University Press.

Peirce, C.S. (1955) *Philosophical Writings of Peirce*. New York: Dover.

Peirce, C.S. (1984-2010). Writings of Charles S. Peirce, volumes 2-8 (Nathan Houser et al., Eds.). Bloomington, IN: Indiana University Press. (writings from c.1867-1890). (Citations use the common form: W vol. page).

Penrose, R. (1990) Précis of The Emperor's New Mind: Concerning Computers, Minds, and the Laws of Physics.. *Behavioral and Brain Sciences*, 13, 4. pp. 643–705.

Perret, N. and Longo, G. (2016) Reductionist perspectives and the notion of information. In: Soto, A.M., Longo, G. and Noble, D. (Eds.) From the century of the genome to the century of the organism: New theoretical approaches (special issue), *Prog Biophys Molecular Biology,* 122, 1. pp. 11–15.

Petitot, J. (1975) Identité et catastrophes (Topologie de la différence). In Lévi-Strauss, C. (1983) *L'identité*. Paris: PUF. pp. 109–156.

Piaget, J. (1945/1962) *Play, dreams and imitation in childhood*. (C.Gattegno & F. M. Hodgson, Trans.). New York: Norton.

Piccinini, G. (2007) Computational modelling vs. Computational explanation: Is everything a Turing Machine, and does it matter to the philosophy of mind? *Australasian Journal of Philosophy*, 85, 1. pp. 93–115.

Piccinini, G. (2017) Computation in Physical Systems. In: Zalta, E.N. (ed.) *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University.

Plato. (1925) Statesman. Philebus. Ion. Translated by Harold North Fowler, W. R. M. Lamb. Loeb Classical Library 164. Cambridge, MA: Harvard University Press.

Plato. (1929) *Timaeus. Critias. Cleitophon. Menexenus. Epistles*. Translated by R. G. Bury. Loeb Classical Library 234. Cambridge, MA: Harvard University Press.

Polanyi, M. (1958) *Personal Knowledge: Towards a Post-Critical Philosophy*. Chicago, Illinois: University of Chicago Press.

Polanyi, M. (1969) *Knowing and Being*. Chicago, Illinois: University of Chicago Press.

Popper, K. (1959) A Propensity Interpretation of Probability, *British Journal for the Philosophy of Science*, 10. pp. 25–42.

Popper, K. (1959b) *The Logic of Scientific Discovery*. London: Hutchinson.

Popper, K. (1963) *Conjectures and Refutations: The Growth of Scientific Knowledge*. London: Routledge.

Popper, K. (1972) *Objective Knowledge: An Evolutionary Approach*. Oxford: Oxford University Press.

Pouget, A.; Dayan, P. and Zemel, R. (2000) Information processing with population codes. *Nat. Rev. Neurosci*, *1*. pp.125–132.

Press, W.H. (1978) Flicker noises in astronomy and elsewhere. *Comments Astrophys,* 7,4. pp. 103–119.

Prigogine, I. (1961) *Introduction to Thermodynamics of Irreversible Processes*.: New York: Interscience.

Prigogine, I. (1978) Time, Structure, and Fluctuations. *Science New Series*. 201, 4358. pp. 777-785.

Prigogine, I. and Stengers, I. (1984) *Order out of Chaos Man's New Dialogue with Nature*. London: Flamingo Edition.

Prigogine, I. (1996) The Laws of Chaos. *Review (Fernand Braudel Center)*. 19, 1. pp. 1–9.

Qiu, X. (2000) *Chinese Writing*. Berkeley: Society for the Study of Early China.

Quine, W.V.O. (1969) 'Epistemology Naturalized.' In: Ontological Relativity and Other Essays. New York: Columbia University Press. pp. 69–90.

Ramsey, F.P. (1931) *The Foundations of Mathematics and Other Logical Essays.* London: Routledge and Kegan Paul.

Rabinow, P. and Rose, N. (2006) Biopower Today. *BioSocieties*, 1, 2. pp. 195–217.

Rao, C., Wolf, D. and Arkin, A. (2002) Control, exploitation and tolerance of intracellular noise. *Nature*, 420, 6912. pp. 231–237.

Raser, J. and OShea, E. (2005) Noise in gene expression: origins, consequences, and control. *Science*, 309, 5743. pp. 2010–2013.

Reichenbach, H. (1949) *The Theory of Probability*. Berkeley: University of California Press.

Reiss, E. (1983) *Cascading Bifurcations. SIAM Journal on Applied Mathematics*, 43, 1. pp. 57-65.

Richards, D. (ed.) (2000) *Political Complexity: Nonlinear Models of Politics*. Michigan: The University of Michigan Press.

Riley, M.A. and Turvey, M (2002) Variability of determinism in motor behaviour. *J Mot Behav,* 34. pp. 99–125.

Rochberg-Halton, F. (1998) Babylonian Horoscopes: The Texts and their Relations. In: Semage, L. (2017) Recommender Systems with Random Walks: A Survey. *ArXiv, abs/1711.04101*.

Romeike, F. and Eicher, A. (2016) Predictive Analytics: Looking into the future, *RiskNET*. pp. 168-171.

Rosen, R. (1977) *Fundamentals of Measurement and Representation of Natural Systems*. New York: Elsevier North-Holland.

Rosen, R. (2000) *Essays on life Itself.* New York: Columbia University Press.

Rössler, O.E. (1998) *Endophysics: The World as an Interface*. Singapore: World Scientific.

Ruelle, D. (1991) *Chance and Chaos*, Princeton NJ: Princeton University Press.

Russell, B. (1996). Determinism and physics. In J. G. Slater & P. Köllner (Eds.), *A fresh look at empiricism 1927–42*. London: Routledge.

Salthe, S. (1993) *Development and Evolution*. Cambridge, MA: MIT Press.

Sanders, T.I. and McCabe, J.A. (2003) *The Use of Complexity Science. A Survey of Federal Departments and Agencies, Private Foundations, Universities, and Independent Education and Research Centers*. Washington, D. C.: Washington Center for Complexity and Public Policy.

Savage, L.J. (1954). *The Foundations of Statistics*. New York, NY: Dover Publications.

Schwartz, H. (2011) *Making Noise - From Babel to the Big Bang and Beyond*. New York: Zone Books.

Scheidl, T., Ursin, R., Kofler, J., Ramelow, S., Ma, X., Herbst, T., Ratschbacher, L., Fedrizzi, A., Langford, N.K., Jennewein, T. and Zeilinger, A. (2010) Violation of local realism with freedom of choice. PNAS, 107, 46. pp. 19709–19713.

Schelling, F.W.J. (1856-61) *Sämmtliche Werke*. ed. K.F.A. Schelling, Stuttgart and Augsburg: J.G. Cotta Verlag.

Schelling, F.W.J. (1858) *Philosophie der Offenbarung*. ed. K.F.A. Schelling. Vols. 1 & 2. Darmstadt: Wissenschaftliche Buchgesellschaft.

Schelling, F.W.J. (1958) *Werke*, ed. Manfred Schröter. Munich: Beck.

Schelling, F.W.J. (1997) Erlangen Lectures 1: On the Nature of Philosophy as Science, tr. Marcus Weigelt in Rüdiger Bübner, ed., *German Idealist Philosophy*. London: Penguin.

Schelling, F.W.J. (1969) *Initia Philosophiæ Universæ*. Edited with commentary by Horst Fuhrmans. H. Bouvier: Bonn.

Schmidt, E., and Cohen, J. (2013) *The New Digital Age, Reshaping the Future of People*. New York: Nations and Business, Alfred A. Knopf. [E-book]

Schnorr, C.P. (1971a) A unified approach to the definition of random sequence. *Math. Systems Theory*. 5. pp. 246-258.

Schnorr, C.P. (1971b) *Zufälligkeit und Wahrscheinlichkeit*. Berlin-Heidelberg-New York: Springer Verlag.

Schnorr, C.P. (1973) Process complexity and effective random tests. *Journal of Computer and System Sciences*. 7. pp. 376–388.

Schnorr, C.P. (1977) A survey of the theory of random sequences. In Butts, R.E. and Hintikka, J. (Eds.) *Basic Problems in Mathodology and Linguistics*. Dordrecht: D. Riedel. pp. 193-210.

Schroff, G. (2015) *The Intelligent Web: Search, Smart Algorithms, and Big Data*. Oxford: Oxford University Press.

Serres, M. (1980) *Le parasite*. Paris: Grasset.

Shadlen, M.N. and Newsome, W.T. (1998) The variable discharge of cortical neurons: Implications for connectivity, computation, and information coding. *J. Neurosci. 18*. pp. 3870–3896.

Shafaieh, C. (2019) "We were never considered fully human, so why should we care about this crisis?" Rosi Braidotti on collective positivity in the face of human extinction . Harvard University Graduate Schools of Design. [online] Available from: https://www.gsd.harvard.edu/2019/03/we-were-never-considered-fully-human-so-why-should-we-care-about-this-crisis-rosi-braidotti-on-collective-positivity-in-the-face-of-human-extinction/ [Accessed 24 September 2020]

Shani, G., Heckerman, D. and Brafman, R.I. (2005) An MDP-based recommender system. *Journal of Machine Learning Research*, 6. pp. 1265–1295.

Shannon, C.E. (1948) A mathematical theory of communication. *Bell Syst. Tech. J. 27*. pp. 379–423.

Shannon, C. (1949) Communication Theory of Secrecy Systems. Declassified Document.

Shannon, C. (1949b) Communication in the presence of noise. *Proc IRE* 37. pp. 10–21.

Shmueli, G. (2017) Analyzing Behavioral Big Data: Methodological, practical, ethical, and moral issues. *Quality Engineering*. 29,1. pp. 57-74.

Simon, H.A. (1957) Models of man. New York: Wiley.

Simon, H.A. (1962) The Architecture of Complexity. *Proceedings of the American Philosophical Society*, Vol. 106, No. 6. pp. 467-482

Simondon, G. (1958/1980), *On the Mode of Existence of Technical Objects*, Trans. by N. Mallahphy, London: University of Western Ontario.

Simondon, G. (1958/2012) *Du mode d'existence des ojects techniques*. Paris: Aubier.

Simondon, G. (1964) *L'individu et sa genèse physico-biologique*. Paris: Presses Universitaires de France. Original Translation by Taylor Adkins.

Simondon, G. (1992) *The Genesis of the Individual.* In: Crary, J., Kwinter, S. (Eds.) Incorporations. New York: Zone Books.

Simondon, G. (2005) *L'individuation à la lumière des notions de forme et d'information*, préface de J. Garelli. Paris: Millon.

Simondon, G. (2007) *L'individuation psychique et collective*. Paris: Editions Aubier.

Simondon, G. (2009) The position of the problem of ontogenesis. *Parrhesia* Number 7, 4–16.

Simondon, G. (2012) *Technical Mentality*. In A. De Boever et al. (Eds.), Gilbert Simondon: Being and Technology. Edinburgh: Edinburgh University Press. pp. 1–15.

Simondon, G. (2017) *On the modes of existence of the technical objects*. Malaspina C and Rogove J (trans.). Minneapolis: Univocal Press.

Smith, C. (1998) *The Science of Energy: A Cultural History of Energy Physics in Victorian Britain*. Chicago: University of Chicago Press.

Solé, R.V. and Goodwin, B. (2008) *Signs of Life: How Complexity Pervades Biology*. New York: Basic Books.

Solé, R.V., Manrubia, S.C., Luque, B., Delgado, J. and Bascompte, J. (1996) Phase transitions and complex systems: Simple, nonlinear models capture complex systems at the edge of chaos. *Complexity*, 1. pp. 13-26.

Sparrow, B., Liu, J., Wegner, D.M. (2011) Google effects on memory: cognitive consequences of having information at our fingertips. *Science*, 333. pp. 776–778.

Speilkamp, M. (2017) Inspecting algorithims for bias. MIT Technology Review. [online]. Available from: https://www.technologyreview.com/s/607955/inspecting-algorithms-for-bias/ [Accessed 18 April 2020]

Sperber, D. and Wilson, D. (1986) *Relevance: Communication and cognition*. Oxford: Blackwell.

Spencer-Brown, G. (1953a) Statistical Significance in Psychical Research. *Nature*, 172. pp. 154-156.

Spencer-Brown, G. (1953b) Answer to Soal et al. *Nature*, 172, pp. 594-595.

Spencer-Brown, G. (1957) *Probability and Scientific Inference*. London: Longmans Green.

Spencer-Brown, G. (1969) *Laws of Form*. London: Allen and Unwin.

Srnicek, N (2016) *Platform Capitalism*, Cambridge: Polity Press.

Stark, D. (2009) *The Sense of Dissonance: Accounts of Worth in the Economic Life*. Princeton: N.J. Princeton University Press.

Strate, L. (2017) Time-Binding in Oral Cultures. *ETC.: A Review of General*

Semantics, 74, 3-4. pp. 431- 445.

Steyerl, H. (2016) A Sea of Data: Apophenia and Pattern (Mis-)Recognition. *e-flux journal #72*. [online] Available from: https://www.e-flux.com/journal/72/60480/a-sea-of-data-apophenia-and-pattern-mis-recognition// [Accessed 18 April 2020]

Sterelny, K., Smith, K.C. and Dickison, M. (1996) The extended replicator. *Biol Philos,* 11. pp. 377–403.

Stern, J.M. (2011). Spencer-Brown vs. probability and statistics: Entropy's testimony on subjective and objective randomness. *Information*, 2. pp. 277-301.

Stiegler, B. (2015) Automatic Society 1: The Future of Work – Introduction. *La Deleuziana: Online Journal of Philosophy*, 1. pp. 121–140.

Stiegler, B. (2019) *The Age of Disruption: Technology and Madness in Computational Capitalism*. Cambridge: Polity Press.

Strogratz, S. and Watts, D. (1998) Collective dynamics of "small world" networks. Nature, 393. pp. 440-442.

Strutt, R. J. (1924) *John William Strutt: Third Baron Rayleigh*. London: Edward Arnold.

Swain, P., Elowitz, M. and Siggia, E. (2002) Intrinsic and extrinsic contributions to stochasticity in gene expression. *Proc Natl Acad Sci U S A*, 99. pp. 12795–12800.

Swerdlow, N (Ed.), *Ancient Astronomy and Celestial Divination*. Chicago: Chicago University Press.

Taleb, N.N. (2010) *The Black Swan: Second Edition: The Impact of the Highly Improbable*. New York: Random House Publishing Group.

Taleb, N.N. (2012) *Antifragile: Things That Gain from Disorder*. New York: Random House Publishing Group.

Thatcher, J., O'Sullivan, D. and Mahmoudi, D. (2016) Data colonialism through accumulation by dispossession: New metaphors for daily data. Environment and Planning D: *Society and Space*, 34, 6. pp. 990–1006.

Thom, R. (1972) Structural Stability and Morphogenesis. Reading, MA: Benjamin.

Thom, R. (1976) Crise et catastrophe. Communications Année 1976, 25, pp. 34–38.

Thom, R. and Chumbley, R. (1983) Stop Chance! Silence Noise! *Determinism*. 12, 3. pp. 11-21.

Thom, R. (1986) 'Préface' to Laplace (1814) cit.

Thom, R. (1990) Postface au débat sur le déterminisme. In Amsterdamski S. et al. (1990) cit., pp. 266–279.

Thom, R. (1991) Aristote et l'avènement de la science moderne: la rupture galiléenne. In: Sinaceur, A. (ed.) *Penser avec Aristote*. Toulouse: Éditions Érès. pp. 489–494.

Thornton, T.L. and Gilden, D.L. (2005) Provenance of correlations in psychological data. *Psychon Bull Rev,* 12, 3. pp. 409–441.

Tiqqun (2020) *The Cybernetic Hypothesis*. Los Angeles: Semiotext(e).

Torre, K. and Wagenmakers, E.J. (2009) Theories and models for 1/f β noise in human movement science. *Hum Mov Sci,* 28, 3. pp. 297–318.

Tribus, M. and McIrvine, E.C. (1971) Energy and Information. *Scientific American*. 224, pp. 179-188.

Tsimring, L. (2014) Noise in biology. *Rep Prog Phys* 77, 2. 026601.

Tsuda, I. (2001) Toward an interpretation of dynamic neural activity in terms of chaotic dynamical systems. *Behavioral and Brain Sciences*, 24, 5. pp. 793-810.

Turing, A.M. (1936) On computable numbers with an application to the Entscheidungsproblem. *Proc Lond Math Soc*, 42. pp. 230–265.

Turing, A.M. (1939) Systems of Logic Based on Ordinals. *Proceedings of the London Mathematical Society*. pp. 161–228.

Turing, A.M. (1952) The chemical basis of morphogenesis. Philosophical transactions of the royal society of London. *Series B, Biological Sciences*, 237, 641. pp. 37–72

University of Illinois College of Engineering (2018) Engineering bacteria to exhibit stochastic turing patterns: first in-vivo proof of principle that patterns can be stabilized by noise. ScienceDaily. [online] Available from: https://www.sciencedaily.com/releases/2018/06/180621121857.htm [Accessed 18 April 2020]

van Belle, G. (2008) *Statistical rules of thumb*. Hoboken, NJ: Wiley.

Vandermeersch, L. (1974) Dalla tartaruga all'achillea (Cina). In: Vernant, J.P., Vandermeersch, L., Gernet, J., Bottéro, J., Crahay, R., Brisson, L., Carlier, J., Grodzynski, D. and Retel Laurentin, A. (Eds.) *Divination et Rationalité*, Paris: Seuil. pp. 27–52.

van Der Ziel, A. (1954) *Noise*. Englewood Cliffs, NJ: Prentice-hall.

van Orden, G.C., Holden, J.G. and Turvey, M.T. (2003) Self-organization of cognitive performance. *J Exp Psychol Gen*, 132. pp. 331–350.

van Orden, G.C., Holden, J.G. and Turvey, M.T. (2005) Human cognition and 1/f scaling. *J Exp Psychol Gen*, 134. pp. 117–123.

Verbeek, P.P. (2011) *Moralising technology: understanding and designing the morality of things*. Chicago: University of Chicago Press.

Vernant, J. P. (1974) Parole e segni muti. In: Vernant, J.P., Vandermeersch, L., Gernet, J., Bottéro, J., Crahay, R., Brisson, L., Carlier, J., Grodzynski, D. and Retel Laurentin, A. (Eds.) *Divination et Rationalité*, Paris: Seuil. pp. 5–24.

Vilar, J., Kueh, H., Barkai, N. ans Leibler, S. (2002) Mechanisms of noise-resistance in genetic oscillators. *Proc National Academy of Sciences of the U S A*, 99, 9. pp. 5988–5992.

Voegelin, S. (2010) *Listening to Noise and Silence*. New York: Continuum

von Foerster, H. (1960). On self-organising systems and their environments. pp. 31–50 in *Self-organizing systems*. M.C. Yovits and S. Cameron (Eds.), London: Pergamon Press.

von Mises, R. (1919) Grundlagen der Wahrscheinlichkeitsrechnung. *Mathematische Zeitschrift*. 5. pp. 52–99.

von Mises, R. (1957) *Probability, Statistics and Truth*. New York: Dover.

von Neumann, J. (1951) Various Techniques Used in Connection with Random Digits, Monte Carlo Method, *National Bureau of Standards Applied Mathematics Series*, 12, pp. 36–38. Washington, D.C.: U.S. Government Printing Office.

von Neumann, J. (1955) *Mathematical Foundations of Quantum Mechanics*. Princeton: Princeton University Press.

Wegner, P. (1997) Why interaction is more powerful than algorithms. *Communications of the ACM 1997*, 40. pp. 80-91.

Weidmann, N. B., Benitez-Baleato, S., Hunziker, P., Glatz, E., and Dimitropoulos, X. (2016) Digital discrimination: Political bias in Internet service provision across ethnic groups. *Science*, 353, 6304. pp. 1151–1155.

Whewell, W. (1847) *The Philosophy of the Inductive Sciences*. London: John W. Parker.

Wheeler, J.A. (1989) Information, Physics, Quantum: The Search for Links. In: *Proceedings III International Symposium on Foundations of Quantum Mechanics*. Tokyo. pp. 354–358.

Wheeler, M. (2005) *Reconstructing the cognitive world: the next step*. Cambridge, MA: MIT Press.

Whitehead, A.N. (1978) *Process and Reality: An Essay in Cosmology*. David Ray Griff & Donald W. Sherburne, eds., P&R. London: Free Press.

Whitehead, A.N. (1968) *Modes of Thought*. New York: Free Press.

Wiener, N. (1948) *Cybernetics, or control and communication in the animal and the machine*. Cambridge, MA: MIT Press.

Wiener, N. (1950) *The Human Use of Human Beings: Cybernetics and Society*. Cambridge, MA: The Riverside Press.

Wilcox, L. (2017) Embodying algorithmic war: Gender, race, and the posthuman in drone warfare. *Security Dialogue,* 48, 1. pp. 11–28.

Wilkins, I. (2021) *Irreversible Noise*. Manuscript submitted for publication. Falmouth: Urbanomic.

Wilson, J.A. (1968) Entropy, not negentropy. *Nature*, 219, 5153. pp. 535–536.

Winner, L. (1980) Do artifacts have politics. *Daedalus* 109, 1. pp. 121–136

Wigner, E.P. (1961) Remarks on the Mind-Body Question. In Good I.J. (ed.), *The Scientist Speculates*. New York: Basic Books. pp. 284–302.

Wicken, J.S. (1987) Entropy and information: Suggestions for common language. *Philosophy of Science*, 54, 2. pp. 176–193.

Williamson, B. (2016) Digital methodologies of education governance: Pearson plc and the remediation of methods. *European Educational Research Journal* 15, 1. pp. 35–53

Williamson, J. (2010) *In Defence of Objective Bayesianism*. Oxford: Oxford University Press.

Williamson B (2017) Computing brains: learning algorithms and neurocomputation in the smart city. *Inf Commun Soc,* 20, 1. pp. 81–99

Wilson, E.B. (1952) *An Introduction to Scientific Research*. New York: McGraw-Hill.

Wio, H. and Lindenberg, K. (2003) Noise induced phenomena: a sampler. *Aip Conference Proceedings*. 658. pp.1-60.

Wolfram, S. (1984) Universality and complexity in cellular automata, *Physica D*, 10, 1-2. pp. 1–35.

Wolfram, S. (1995) Origins of Randomness in Physical Systems. *Physical Review Letters*, 55. pp. 449–452.

Wolfram, S. (2002) *A New Kind of Science*. Champaign, IL: Wolfram Media, Inc.

Wolfram, S./ Wolfram Research, Inc. (2020) *Finally We May Have a Path to the Fundamental Theory of Physics… and It's Beautiful*. Available from: https://writings.stephenwolfram.com/2020/04/finally-we-may-have-a-path-to-the-fundamental-theory-of-physics-and-its-beautiful/ [Accessed 18 April 2020]

Wynne, B. (2001) Creating Public Alienation: Expert Cultures of Risk and Ethics on GMOs, *Science as Culture*, 10. pp. 445–81.

Wynne, B. (2005) Reflexing Complexity: Post-genomic Knowledge and Reductionist Returns in Public Science. *Theory, Culture & Society*, 22, 5. pp. 67–94.

Yuan, X., Lee, J.H., Kim, S.J. and Kim, Y.H. (2013) Toward a user-oriented recommendation system for real estate websites. *Information Systems*, 38, 2. pp. 231–243.

Zabell, S.L. (1992) The Quest for Randomness and its Statistical Applications. In Gordon, E. and Gordon, S. (Eds.) *Statistics for the Twenty-First Century*. Washington, DC: Mathematical Association of America. pp. 139-150.

Zenil, H. (2011) The World is Either Algorithmic or Mostly Random. arXiv:1109.2237

[cs.IT]

Zhang, H. and Min, F. (2016). Three-way recommender systems based on random forests. *Knowl. Based Syst*, 91. pp. 275-286.

Zuboff, S. (2015) Big other: Surveillance capitalism and the prospects of an information civilization. *Journal of Information Technology*, 30, 1. pp. 75–89.

Zuse, K. (1969) Rechnender Raum (Calculating Space). *Schriften Zur Dataverarbeitung* 1. Available from PhilArchive: https://philarchive.org/archive/ZUSRR [Accessed 18 April 2020]