



Paper

Thoughts on Nonlinear Systems: Imperfections and Noise towards the Hidden Technologies

Luigi Fortuna ¹ and Arturo Buscarino ¹

¹ *Dipartimento di Ingegneria Elettrica, Elettronica e Informatica, University of Catania, Italy.*

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Abstract: The dynamics of nonlinear systems will be emphasized in order to give focus on how noise and imperfections allow the emergence of novel control systems thanks to the hidden characteristics of a class of nonlinear devices. More experiments and real applications have been discussed during the lecture. In order to give a general perspective of the concept of imperfection, some thoughts are here discussed.

Key Words: imperfection, noise, nonlinear systems, control.

1. Introduction

We are attempting to summarize a research topic that is very close to our hearts: that of imperfect systems [1–5]. The technical and technological aspects of the dynamics of imperfect systems are part of our work as engineers and experimenters. A formalization of imperfect systems and a detailed characterization of them have been developed in recent research, which has also been very enjoyable. The scientific results related to our specific research have been appreciated by attentive and rigorous colleagues from various institutions.

An appropriate and extensive bibliographic review allows us to frame the problem in a broad context, perhaps giving us valuable opportunities for cultural growth.

Let's be direct and perhaps provocative: imperfect systems work! They work surprisingly well. Of course, imperfection always exists, and its seemingly negative effects, in certain cases —though not always — allow us to create reliable objects, and in some cases, unique and irreplaceable in terms of their functionality. Just think for a moment, consider imperfection, within certain limits, not as a negative element, but as a potential added value.

It is not our intention in this note to delve into the analytical details of imperfection. We will try to outline some aspects and some historical notes. Writing will also be an opportunity for us to understand a little more about imperfection, as we try to formulate an essential summary of the ideas we have attempted to synthesize in recent months. A quick search on GOOGLE for "perfect" and "imperfect systems," in Italian or English, results in a dense and disorganized forest of information. By the way... out of curiosity... the Google logo, the well-known G, is not inscribed within a perfect circle as it might seem. An imperfection that intrigues us, adding to the mystery of our search engine!



It's Google's imperfection. Many of us consider it a perfect platform!

Now, let's begin. The synthesis we intend to create starts with an ancient and classic definition of what is imperfect: "imperfect is that which is not perfect." It's time to refer to the definition of perfection attributed to Aristotle. In the fifth book of *Metaphysics* [6], the philosopher clarifies the "fundamental philosophical lexicon," including the definition of perfection. The fourteen treatises on *Metaphysics* were compiled and published by Andronicus of Rhodes nearly a century before Christ. Another curiosity: the term "perfection" is not present in the *Enciclopedia Universale dell'Arte* [7] published by Sansoni, a discovery that surprised us.

Returning to Aristotle, perfect is:

- that which implies completeness;
- that which implies the concept of the best in an intrinsic sense, meaning that nothing better could exist;
- that which has absolutely achieved the intended objectives.

A chronological and thorough analysis of Aristotle's concept of perfection is well-documented and intensively treated in the history of philosophical thought. For now, it's enough to keep these postulates in mind so that, as we discuss imperfection, we can avoid unnecessary confusion. From an analytical point of view, a quantitative assessment is needed for an imperfect system, but for now, it's not essential to go into detail on this.

At this point, we'll start by presenting one of the most beautiful images we recently considered: the one at the beginning of this note. The photo will allow us to initiate a future discussion precisely on how "imperfection" can be a driving force toward deeper knowledge. The image mentioned is provided by Hubble [8]. Hubble is a space telescope launched into orbit in 1990. It's still operational, with its successor expected to be launched in May 2020. The photo in question is the so-called "Hubble Ultra Deep Field." It shows more than one hundred of the most distant red galaxies ever captured by an optical telescope. Observing it gives us a sense of wonder, as it allows us to see time: over 13 billion years... almost the age of the universe. The HUDF followed the HDF (Hubble Deep Field), which is considered a milestone in cosmology.

But how did the HDF come about? It resulted from a continuous observation over 10 days between December 18 and December 28, 1995. Why? The HDF photo encompasses an area comparable to a $\frac{1}{4}$ -degree geometric arc. It's a point where Hubble seemingly saw nothing! A region that, referring to Aristotle, characterized the incompleteness of Hubble's "old" images. This incompleteness, imperfection, led scientists to point the instrument at that tiny region in Ursa Major where nothing seemed to appear! An imperfection, an incompleteness led to more closely exploring that small portion of space. And thus, the observation, accumulated over 10 days in a "void" region of our Milky Way, provided us with the most distant observations of other galaxies.

Three years after the HDF observations, a similar image was taken, directing Hubble to the opposite hemisphere, the universe indeed has symmetries!

The HUDF image highlighted above was born from an even deeper observation in 2004. Then in 2012, additional observations over 23 days characterized the HUDF, an image in the center of the previous one that allows us to glimpse images of galaxies dated to 13.2 billion years ago.

From the incompleteness of an image, from an apparently completely dark point, from an imperfection, we now have one of the most accurate images of the universe, a testament closest to the universe's age. What will Hubble's successor reveal?

Hubble is known as a telescope, named after Edwin Hubble, a famous American astronomer who also lived in Italy. From an imperfection, a lack of completeness, we obtained perhaps the most important image of the universe, a testament to its age—13.2 billion years!

Let's reflect on this number.

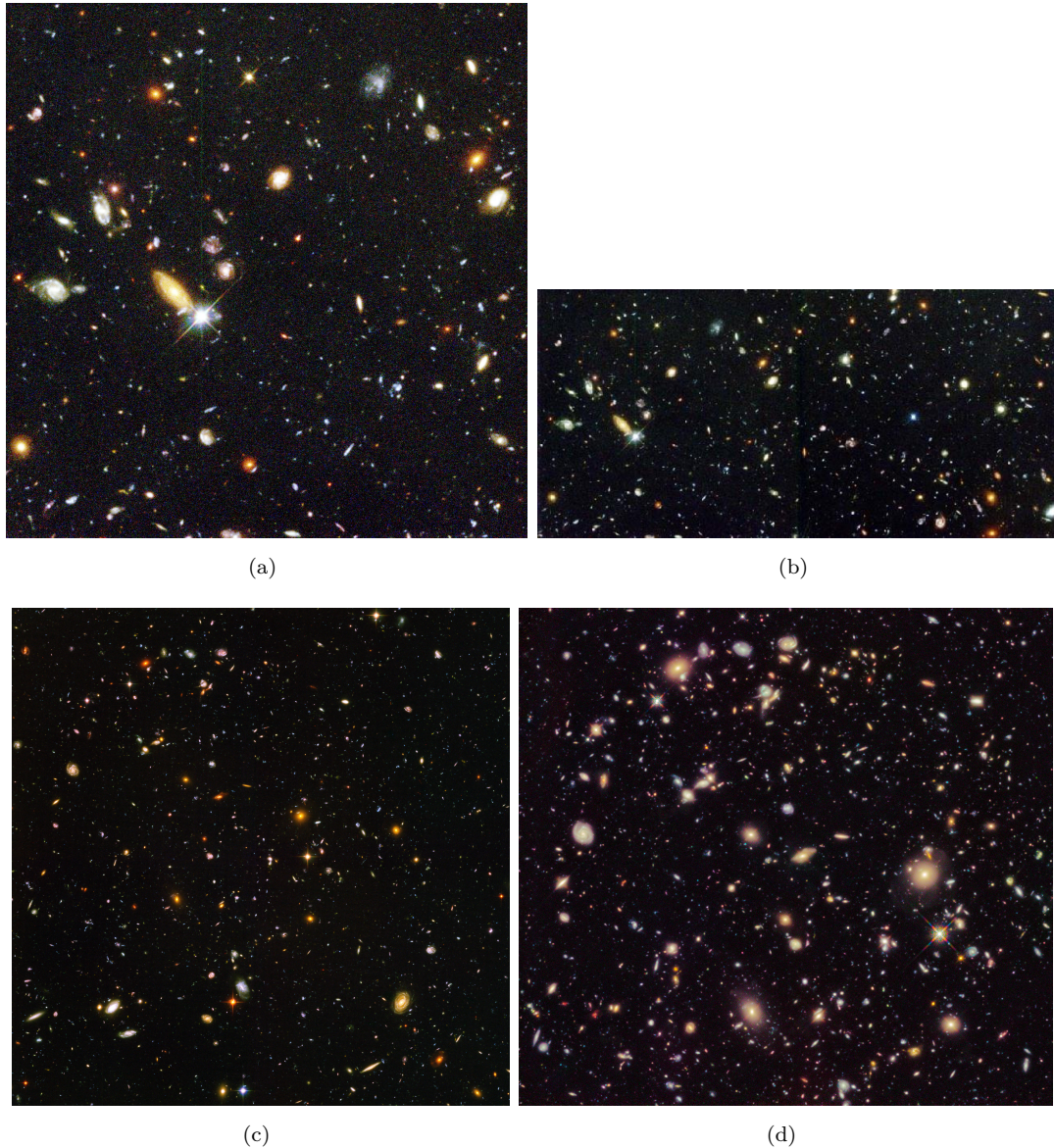


Fig. 1. Hubble deep field observations: (a) 1995, (b) 1998, (c) 2004, and (d) 2012.

2. Ideas from the Greek Myth

An Attic vase dating back to around 550 BC particularly caught our interest in May 1983 during a visit to the Louvre Museum in Paris. The artifact depicts the scene where Thetis hands Achilles the weapons forged for him by Hephaestus.

Hephaestus is certainly not the stereotype of perfection in Greek culture. Imperfection was not mentioned in ancient Hellenistic culture. But it was possible in Greek mythology. As Flavius Sallustius wrote about myth "*these things never happened, but they are forever.*"

Hephaestus is the god of fire, his tragic story presenting him as lame, deformed, and rejected. Cast out of Olympus into the oceans, he was lovingly welcomed by the Nereids, especially by Thetis. Although not perfect by classical standards, Hephaestus was adored for his engineering and crafting abilities. Moreover, he was a great manual laborer; Hephaestus, who perhaps walked with a cane, possessed prodigious strength. His many works included a workshop believed to be close to us: deep within Mount Etna.

To orient ourselves, we're in the Iliad [9], book eighteen, we'll summarize in a few lines what we need for this note.

Thetis, Achilles' mother, is desperate. Her son wants to return to war. The Iliad is a poem of



Fig. 2. Attic vase depicting Thetis handing Achilles the weapons forged by Hephaestus (Louvre Museum, Paris).

wrath, and Achilles has decided. Only Hephaestus, whom Thetis, raised as a son, can help her.

Thetis goes to Hephaestus and begs him to craft for Achilles an invincible shield and weapons. Hephaestus, sweaty, heated, and tired from his labors, barely holding himself up, listens to Thetis and grants her request. He makes a shield that challenges not only technological perfection but goes beyond. It uses five layers of bronze, tin, and gold. He represents everything... even the ocean. It is a shield, complete, in the sense of completeness discussed in our previous note.

At this point, we've framed the perfect-imperfect dichotomy, applying this duality to humans and objects.

Hephaestus conceived in his work automata, machines capable of replacing humans in dangerous and repetitive tasks. He made Talos as a gift to Minos. Talos was the guard of Crete, invulnerable but imperfect. A defect in one heel led to his demise.

From the meeting of Thetis with Hephaestus, the presence of the master's two handmaidens stands out. Here is Vincenzo Monti's translation of the relevant Iliad passage:

[...]seguian l'orrido rege, e a dritta e a manca il passo ne reggean forme e figure di vaghe ancelle, tutte d'oro, e a vive giovinette simili, entro il cui seno avea messo il gran fabbro e voce e vita e vigor d'intelletto e delle care arti insegnate dai Celesti il senno[...]

(the horrid king was followed, and to right and left the way was governed by lovely maidens, all of gold, who seemed to live, in whose breasts the great forger had placed speech, life, and vigor of mind, and celestial intelligence to instruct them in cherished arts)

And here the duality appears again: imperfect Hephaestus seeks perfection in his handmaidens, endowing them with wisdom. Perhaps Hephaestus was the father of robotics and artificial intelligence?

Jean-Pierre Vernant, one of the most profound scholars of myth, wrote in one of his books [10] that he wanted to recount the story of myth as a long tale, just as he used to every evening, first to his children and then to his grandchildren. In doing so, we too have learned something.

Certainly, we could never compare ourselves to the illustrious Jean-Pierre, but we would like to speak of imperfections as if telling a lighthearted tale, even though we realize, as we continue, that we face many challenges.

Forgive us, dear readers, for any imperfections.

3. Ideas from literature

Before this note on the specific theme, you might remember the two previous notes, which referred respectively to an image of an imperfect universe and imperfection in Greek mythology. The topic interests us because, working in engineering and technology, we've often found that the tendency to design perfect systems is neither useful nor realistic. We believe most systems work because of their imperfections and the self-organized functionality that results from them.

So, we thought we would reflect on the topic by sharing a series of notes. This is the third; a fourth will follow, and then we will spare you further reflections on these peculiar and imperfect themes.

We had considered discussing art and imperfections in this note — a theme too vast — and besides, how many perfect critiques might there be.

Thus, we chose to dedicate some reflections to a particular literary genre: diaries.

They are imperfect according to literary stereotypes: often fragmented, with temporal gaps, and heterogeneous in their themes. And yet, they reflect the essence of the author. Many of us keep a diary, writing a page from time to time. They are a portrait of ourselves. We keep them hidden, scattered on sheets of paper. Some keep them in their minds, re-reading them in solitude, sometimes even sharing them. Disorganized, perhaps written in a rush, diaries in their incompleteness are our memory; they mark time with delicate lightness and relentless truth.

This is why we thought of referring to diaries almost as a tribute to their intrinsic imperfection.

But which diaries?

Consider two fundamental examples: *This Business of Living* (*Il mestiere di vivere*) by Cesare Pavese [11] and *The Book of Disquiet* (*Livro do Desassossego*) by Fernando Pessoa [12].

We have read and re-read the former many times, recently with greater attention, searching for any linguistic hint of perfection or imperfection — terms we haven't yet encountered in our reading, perhaps waiting for them to appear. . “Aspettare è ancora una occupazione. E' non aspettare niente che è terribile” (Waiting is still an occupation. Not waiting for anything is what's terrifying.) (Diary of September 15, 1946). And so, as we wait, we recall a book by Pavese: *Dialoghi con Leucò* (*Dialogues with Leucò*) [13].

In the literary world, *Dialogues* itself is considered an imperfection, according to a recent review. There are 27 dialogues — brief, essential, expressive chats — between two interlocutors. Pavese gives voice to figures from Greek mythology, like Tiresias, Oedipus, Chimera, Calypso, Odysseus, Thanatos, and Achilles. Fragility, strength, life, death, nature — these themes are revisited and offered to the contemporary reader through the device of dialogue steeped in mythology. Universal themes brimming with passion, which Pavese perhaps dedicates to his muse, Bianca Garufi. Leucò is the goddess Bianca but also a name derived from Leucothea. A curiosity: in the *History of Italian Literature* [14] published by Garzanti, not a single line is devoted to this work, today considered perhaps the most important by many—a flaw, an imperfection.

The dialogue allows multiple characters to have a voice and enables a lucid expression of doubts and uncertainties, bringing memories to life like a form of waiting.

In our bag of unpublished notes, we have sometimes proposed invented dialogues, born of imagination and projected onto the understanding of ourselves. Certainly imperfect, as they are incomplete and a reflection of our mood at the time, it was enjoyable to write them, inventing instantly and then crafting questions and answers, immersing ourselves immediately in the reality of the characters in the dialogue.

More technical and less immediate are Gregory Bateson's *Metalogues* [15]: imaginary conversations that never end with certainty.

From *The Book of Disquiet*: “We adore perfection because we cannot have it: we would hate it if we did. The perfect is inhuman because the human is imperfect” (Fragment 286, 1936). *The Book of Disquiet* is an autobiography told in a diary written by heteronyms invented by Pessoa, among them Bernardo Soares, and reconstructed by Jerónimo Pizarro into 445 numbered and dated fragments. The reconstruction of the text, composed of sheets lying in a trunk waiting to be revisited, is the emergence of a noble soul.

Pessoa's masterpiece, generated from a life dedicated to reflection and the constant questioning of himself on universal themes, is perhaps the truest and most ingenious fiction in world literature.

Each man and woman lives are immersed in a hidden disquiet, then they are pierced by a sunset different from any other, in the face of such beauty, the disquiet momentarily yields to dreams. “*Everything is imperfect; there is no sunset so beautiful that it could not be more so*” (Pessoa).

4. Ideas from Neuroscience

Blue Tree is a painting by Piet Mondrian.

When we began writing this series of notes on Imperfection, we had several themes in mind that



Fig. 3. Blue tree by Piet Mondrian.

we wanted to discuss with you. Many scattered notes were summaries of essays on the subject. Many ideas and reflections on Imperfection accumulated day after day. The comments of those who read the previous notes broadened our imperfect horizons of knowledge. We would like to continue sharing at length.

True and heartfelt stories, however, have a brief conclusion.

When we have to present the summary of scientific research, the time available is limited. We must manage the time appropriately. It has become an imperfect habit to accelerate the conclusion, perhaps without fully detailing and explaining the most interesting aspects due to time constraints. Each time, we promise ourselves to do better “next time.” Forty years have passed since we began the craft of sharing “study,” and we continue to be imperfect, but we always hope to improve.

Forgive us if, in concluding this discussion on Imperfection, we fall into that classic recurring mistake.

Rita Levi Montalcini, in our opinion the most prestigious neuroscientist we have read, an exemplary model of a woman, titled her autobiography *In Praise of Imperfection (Elogio dell’Imperfezione)* [16].

Lamberto Maffei, another Italian neuroscientist, in his book *The Freedom to Be Different (La libertà di essere diversi)* [17], highlights how cerebral noise, always present in living beings, is almost nonexistent in biologically less evolved creatures, reaching significant levels in our brains, both when we are awake and during various stages of sleep. A paradox of imperfection?

“Il rumore cerebrale è probabilmente una specie di suggeritore continuo che sta alla base della generazione della varietà e della novità del pensiero, in una parola della creatività” (Cerebral noise is probably a sort of continuous prompter that underlies the generation of variety and novelty of thought — in a word, creativity)

In most of the works of one of our favorite authors, neurologist Oliver Sacks, imperfection — that is, neurological deficits — brings forth the astonishing ability of our central nervous system to express unimaginable adaptive capacities [18]. Even a terrible migraine can leave its victim with traces of unexplored pathways in the mind of which they are the sole, fiercely protective owners.

Reflecting on these last three examples of remarkable imperfection, we remain reverently silent and in awe.

5. Conclusions

This contribution is included in the lecture on “Nonlinear systems: imperfections and noise towards hidden technologies” given at NOLTA 2024 to give focus on general aspects of the positive effects of imperfections in various fields.

The paper has the aim of making a link among dynamical nonlinear systems and disciplines like literature, humanities and mind science. It gives only some flashes on the subject, but it could represent a stimulus for further insights in the area of imperfect systems.

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