Dialogues on the New Physics

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Complexity and Nonlinearity in Nature

By

J. R. Croca

Cambridge Scholars Publishing

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This work is dedicated:

– To the young, generous and enterprising spirits, freed from dogmatic, obscure and conservative prejudices.

– To all those who recognize the profound interdependence between the complex entities in which the human being is included, and for that reason give priority to cooperation rather than aggression.

These are, in fact, the builders of the true progress of mankind.

To my granddaughter Teresa

J. R. Croca

Contents

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INTRODUCTORY NOTE

The book that is now presented to the reader is the continuation of the previous Dialogues – *Dialogues on Quantum Physics, from Paradoxes to Nonlinearity*.[1]

The first version of the Dialogues was mainly intended to present to the general public, not only a more simplified version from the formal point of view of the ideas contained in *Towards a Nonlinear Quantum Physics*[2] but also to develop with a little more detail certain historical and epistemological aspects related to the foundations of quantum physics.

Like the first volume, this second volume of *Dialogues – Dialogues on the New Physics, Complexity and Nonlinearity* – aims to bring to the general public in a relatively accessible way, even those people without great mathematical preparation, the ideas contained in the book *Eurhythmic Physics or Hyperphysics, the Unification of Physics*.[3] In this work, a proposal for a global and unifying view of physics is presented.

It's a new way of looking at nature, the physis, based on the organizational genetic principle of eurhythmy. In this perspective, traditional physics, quantum physics, relativistic physics and classical physics can be seen as a particular cases of the new relational physics of the complex and nonlinear. In addition, the new physics or eurhythmic physics also aims to build a bridge between those commonly called hard or exact sciences and the sciences that treat highly complex systems. From these, we can refer to the human and social sciences – psychology, sociology, economics, etc.

In these sciences, which deal essentially with complex systems, the whole is generally quite different from the sum of its constituent parts. Under these conditions, these systems are generally not susceptible to an adequate treatment within the traditional simplistic, linear and Cartesian conceptual framework.

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[1] Croca, J. R. and Moreira, R. N. (2014). *Dialogues on Quantum Physics, from Paradoxes to Nonlinearity.* Cambridge, UK: Cambridge International Science Publishing.

[2] Croca, J. R. (2002). *Towards a Nonlinear Quantum Physics.* Singapore: World Scientific Publishing.

[3] Croca, J. R. (2015). *Eurhythmic Physics or Hyperphysics: the Unification of Physics.* Berlin, Germany: Lambert Academic Publishing.

In the Guise of an Introduction

The new version of the Dialogues, which I now have the opportunity and the honour to present to the reader enlightened and motivated by matters of science and knowledge in general, corresponds to the continuation of the fruitful and interesting discussion meetings on the foundations of the new physics which I've carefully recorded over time. Once again, I begin by asking the reader's indulgence for my rather crude and little refined prose. As I mentioned in the first version of the Dialogues, I don't have a great literary background because I'm an engineer.

Due to the needs of my profession I've been more in contact with the practical applications of science. However, not for a moment have I lost interest in the meaning and origin of the practical rules that we use in solving the real problems that arise in our day-to-day lives. Moreover, I'm convinced that this natural tendency to look for the origin or the meaning of things and not to content myself with the uncritical use of a set of recipes, of practical rules, was a precise and important reason for my professional and economic successes.

The first version of the Dialogues, which I was pleased to present, corresponds to the discussions around the foundations of quantum physics, in its traditional indeterministic or bohrean interpretation and in its causal and nonlinear formulation. Now, this new version of the Dialogues corresponds, first of all, to the discussions of the School of Lisbon on the extension and generalization of nonlinear quantum physics to the known physics giving rise to the new physics, or eurhythmic physics. This is, in my humble opinion, a revolutionary proposal – a new scientific paradigm – in other words, a new way of looking at nature.

As in the first version, these Dialogues correspond to the systematic narration of the interesting and stimulating journeys of discussion we had in various places and that I was careful enough to register, and now, once again, I am transferring to writing so the reader can also benefit from them.

The characters involved in this new narrative are the same, as the discussion group is essentially the same. However, I have to say that I feel extremely happy for having the opportunity to add the presence of a woman to our initial group. Contrary to a general believe, especially in certain masculine sectors, I am of the opinion that women always had and still continue to play an extremely important role in the progress of humanity.

To confirm this just think, for example, about agriculture. This invention, which is mainly due to women, was undoubtedly one of the most important discoveries made by humankind. Without this step there would be no progress at all. To this feminine element of our group I've attributed the name of Iris for it's mainly related to light, that element that has played and continues to play a fundamental role not only in physics itself but also in the evolution of humanity.

The first version of the Dialogues didn't include women for the obvious reason that there were no women in the discussion group about the foundations of quantum physics. Now, since the Dialogues are a narrative as faithful as possible to what actually happened, there was no reason to falsify it by introducing a woman into it in a perfectly arbitrary and unfounded way.

Only for information to the reader unfamiliar with the first version of the Dialogues, I will briefly mention that the names of the interveners have been Latinised and chosen in a way that seek to translate their attitude towards science and the world as much as possible. From these names I will only mention that of my great friend Argus, whom I ascribe this denomination for being related to this mythological ship which demanded knowledge across unknown universes in an initial instance and, at a later stage, wisdom.

The name I've chosen for myself is Liberius, as I consider myself as a lover of liberty, especially the one that's most difficult to achieve, which is freedom of thought. This is, because right from birth we are formatted by all possible means in a given pattern of thinking. Therefore to depart – even if briefly – from this pattern, this conceptual imprisonment, constitutes in my opinion a truly heroic achievement.

Liberius

Science until the Beginning of the Twenty-first Century

FIRST JOURNEY

We were in mid-September, at the beginning of the academic year, with people coming back from their holidays, some better or worse prepared to tackle the systematic hard work of everyday life again. Following the wishes expressed by the members of our research group, the Lisbon School of Eurhythmic Physics, we would finally continue our discussions around the possibility of elaborating a global interrelational new physics, of the complex and nonlinear. This new physics – more general – where emergency finds its natural place, would have the capacity to integrate the known physics as a particular case, at least with regards to its applications.

As you must understand, I was very excited not just for having the chance to see my dear friends again after a longer absence than I had wished for, but also for the opportunity to resume our interesting and stimulating discussions.

The meeting had been scheduled for Wednesday at about 8.00 p.m. at the Fábrica Braço de Prata. This building, next to the port area of Lisbon is – so to speak – the heiress, the continuation of the Eterno Retorno (*Eternal Return)* bookstore that is currently closed. It's a very spacious place constituting one of the most interesting places of the capital, especially for those who are interested in avant-garde culture in its most varied aspects. In addition to a bookstore and a bar, there are several rooms that can be used for lectures, meetings, concerts, film projections, exhibitions and other cultural activities.

Once arrived, I sat down at the bar and had a beer while I waited for the rest of the group. Soon after Argus arrived, accompanied by Fabrus. They sat at my table and asked for tea, as usual. Promptly, we started the conversation about the holidays with Argus saying that he had spent a part of his vacation at the thermal baths because it was a very quiet place and therefore lent itself wonderfully to the act of thinking. So much so, that when he went on vacation, he'd always take those more difficult problems with him to study which required a much greater effort and dedication. Fabrus was telling how much he had enjoyed himself sailing his yacht when Iris, Amadeus and Lucius arrived. What a feast! Everyone talking at the same time. When things calmed down a little more and the holiday talk lost its initial impetus, we began, as expected, to talk about science.

Following my request to the group to systematize the discussion, Argus began:

Before we begin presenting a proposal for a new physics, for a new way of looking at nature, the physis, it might be convenient to say a few words about what has been, in essence, our science, that is, the traditional science.
Traditional science, also called modern science by many, can be said to have had its beginnings in the seventeenth century, mainly with that great man by the name of Galileo. Naturally, as we all know too well, there was a whole plethora of precursors, of which I shall merely mention Nicholas of Cusa, Copernicus and Maestlin, the mentor of Kepler. For this great achievement, Galileo had to proceed with the unification of physics. Thus, he assumed on the one hand that both the supralunar and sublunar worlds had the same ontological nature and, on the other hand, he had yet to drastically simplify the problems to be dealt with.
Since we have already mentioned its ontological unification in previous discussions, now I will only mention the method, the simplification process he used in solving the problems, namely with regard to the movement of projectiles which is the basis of mechanics. It's worth noting in passing that at the time of Galileo the artillery was in full development. On the other hand, it could be seen that Aristotle's description of the movement of bodies was completely inadequate. As we know, the movement of a projectile fired by a cannon is not composed of linear segments, one inclined and one vertical, as Aristotelian physics intended and as this scheme seeks to indicate (Figure 1-1).

On the paper tablecloth, Argus drew the scheme I am reproducing as faithfully as I possibly can:

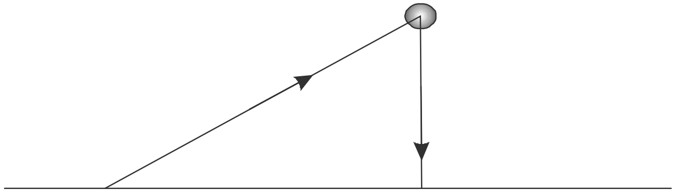

Figure 1-1: Movement of a projectile according to Aristotelian physics.

Argus continued: "Actually, the projectile motion is approximately parabolic, as anyone can observe."

At this point, Lucius decided to intervene.

Indeed, since the motion of projectiles fired by the cannons could be easily observed at the time, it would be very difficult to accept the explanation given by Aristotelian physics and its medieval variants. No one saw a violent inclined linear movement, resulting from an eventual *impetus*, which would be gradually lost, followed by a vertical drop, for the body to follow its 'natural' movement back to Earth. In fact, what was observed was a continuous movement, without any interruption, approximately parabolic, as Argus said.

Argus responded.

Thank you, Lucius, for your clarification! However, it should be borne in mind that it took about two thousand years after Aristotle to solve this problem of projectile motion. To solve it, Galileo had to invent a whole new process, a new way of looking at the world.
It is this process, this radical and fruitful method initiated by Galileo that I want to talk to you about. Since the projectile motion is very complex, Galileo will assume that this complex movement ultimately results from the composition of two more simple and perfectly independent movements: a vertical movement and a horizontal one, being that the complex motion of the projectile results from the simple sum of these two elementary motions. Under these conditions, he will study each one of these movements in a completely independent way. Let us then consider the vertical motion: In this motion, the projectile begins to rise, losing its speed progressively until it reaches a maximum height where the speed is null. Once it has reached this point of maximum height, it then starts to descend until it reaches the ground with a speed equal to that of the launch.
Now let's look at what happens to the horizontal movement: In this case the motion is very simple, always uniform, and naturally starts and ends at the same time as the vertical motion.
So, as can be seen, each part of the problem to be studied – the projectile motion – is of relatively much simpler treatment and its solution almost direct. The more complex total motion to which the body is subject to is then the simple sum of the two movements. In the sketch I am doing here, you can see how to proceed (Figure 1-2).

Argus, who we know is very talented in drawing, moved to the paper tablecloth once again to draw the sketch that I now reproduce as faithfully as I possibly can:

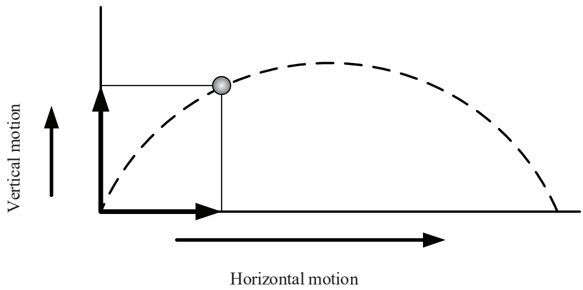

Figure 1-2: Movement of the projectile as a result of two influences.

Argus continued:
So, as you can see, the final motion of the projectile results from the sum of the two motions: the speed of the vertical motion is higher at the beginning and decreases gradually until it reaches the zero value. When the vertical speed of the projectile is zero, the projectile has reached the maximum height, as we know. In the next instant it begins to fall, with an initial speed equal to zero that progressively increases until it reaches the starting value. The horizontal speed of the projectile is constant and lasts the same time as the vertical motion of rise and fall. Note that in this figure only the position of the projectile, on the dotted line, is represented at every instant.
On the other hand, the observation of the relative motion, associated with his way of seeing the world, led Giordano Bruno to the conclusion that the movements of the various bodies could be taken as independent and therefore the process of linear independence was applicable. Thus, the speed for example, of one boat relative to another would be given by the simple difference of their velocities relative to the port, or, for example, in relation to the river banks.
In any case, this process of linearization or independence of the constituent parts of a whole, initiated by Galileo, received a more complete and more general theorization at the hands of Descartes, this great man of thinking. This great thinker will generalize the process initiated by Galileo and make it the lever, the key, in short, the ‘method’ to unveil the secrets of nature. This method, also known

as Cartesian or linear – as already mentioned in our previous discussions – basically consists of the following:
When we have a difficult problem to solve we begin in the first instance by decomposing it, for example into two distinct parts. Next, we will try to solve each of the parts separately. If the solution of these two parts still proves to be difficult, we proceed to a new division and so on until each of the parts can be solved. The final solution will then be the simple sum of the parts. In this process of describing natural phenomena, studying the whole or its constituent parts is exactly the same thing. It's implicitly assumed that the different parts that constitute the whole when in reciprocal interaction do not change. That is to say, whatever the combination, the parts remain perfectly unchanged, thus always maintaining their own identity. Ultimately, as it can be seen, it is a question of assuming total independence between the constituent elements of the whole. Therefore, when in interaction − if we can truly designate this type of composition or combination as an interaction − the constituent elements always maintain their identity without suffering any modification, no matter how small.
From this linear principle of perfect independence and permanence of physical systems, naturally results the principle of action–reaction. This principle states that when an action is exercised on a body, it responds with an equal action in the opposite direction in order to preserve its own identity.

At this moment, Iris, who until now had been very attentively listening to Argus, said, "Argus, I don't quite understand this relationship between the action–reaction principle and the linear principle of total independence of physical systems. Can you explain this subject a little more?"

"With pleasure!" replied Argus, continuing:

In fact, the statement of this principle is the third postulate of Newtonian mechanics. Its form, as enunciated by Newton in his book *Philosophiae Naturalis Principia Mathematica*,[4] is the following:
To every action corresponds always an opposite reaction of equal intensity: or the mutual actions of two bodies upon each other are always equal in magnitude and directed in opposite directions.

[4] Newton, I. (1687). *Philosophiae Naturalis Principia Mathematica.* London, UK.

Another way of enunciating this principle consists of saying: when a force acts on a given body, this responds with equal force of opposite direction.
In the end, what this statement intends to say is that a body – a given physical system – seeks to maintain, above all, its total independence. In these conditions, in order not to lose its identity and to remain as such, it responds to the action exercised on it with an equal force with opposite direction in order to neutralize it. As we will see later on, this principle is only a very particular case of the application of a much more general statement which is the principle of eurhythmy.
In any case, the importance of this linear Cartesian method was clearly assumed by Newton in his *Principia*. Besides postulating the principle of action–reaction as the basis of his mechanics, he also postulates the principle of linear superposition. The principle of addition or linear superposition of forces serves to obtain the force resulting from the action of various forces applied to a physical system. This principle of addition constitutes, as we know, one of the important pillars upon which the whole of Newton's theory rests.

At this point, Fabrus entered the discussion.

At this point, I think it's worth mentioning that the principle of independence of forces, and their addition, is clearly assumed in the so-called parallelogram of forces. This gives nothing but the practical form of determining the resulting force from the action of several independent forces applied on a given point.
Let's consider, for example, the case of a boat in a canal being pulled with a tow rope from the two banks, as seen in this drawing.

With the help of Argus, he drew Figure 1-3, which I am reproducing below.

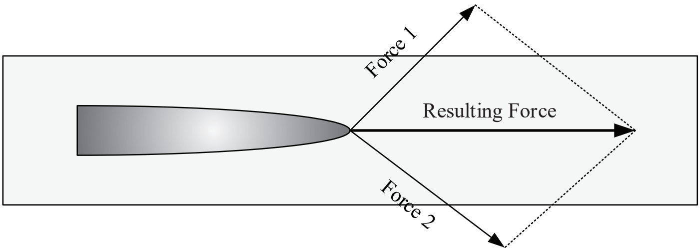

Figure 1-3: Parallelogram of the composition of forces.

Fabrus continued:

The resulting force, that is, the total force pulling the boat along the canal is the linear composition of the two forces considered as independent.
It should be considered, though, that this simple and extremely elegant formalization that students of classical mechanics learn to combine forces and velocities, the so-called vector calculus, only appeared much later in the late nineteenth century, mainly due to the work of Gibbs and Heaviside. I would also like to draw your attention to the fact that, even though vector calculus was not available, the study of mechanics didn't stop its development and application mainly due to the work of Lagrange, the great physicist-mathematician.

After a pause, Argus resumed.

It seems to me that it's still convenient to add to this beautiful explanation given by Fabrus on the parallelogram of forces, the so-called conservation laws of physics, namely the law of conservation of linear momentum proposed by Descartes, the law of conservation of kinetic and potential energy developed by Leibniz and the other conservation laws which have much to do with this principle of linear independence.
On the other hand, also as an implicit consequence of this method we have the fundamental notion, in the traditional physics, of the infinite referential both in space and time. Likewise, the so-called laws of nature, namely the second 'law' which tells us that force is

> proportional to acceleration, the 'law' of universal attraction and others, are assumed to be valid forever and ever, whatever the region of space.

Once again, Iris entered the discussion. "I don't quite understand the notion of 'referential' which seems so be so important after all! I wonder, Argus, if you could explain the subject more clearly ..."

Amadeus and Lucius acknowledged Iris's question, and I, truth be told, also joined forces with them because I think the matter needed to be better clarified.

"My fault!" admitted Argus, "I apologize! You are quite right, a notion as important as that of a referential deserves a deeper explanation."

> Although the origins of this concept can be attributed, among others, to Galileo and Descartes, it was mostly Newton in his book the *Principia*, which I have already mentioned, who postulates the existence of an absolute referential where the laws of physics would be valid. This referential then assumes a primordial status because it would then be some kind of 'stage' where matter would perform its role according to the immutable laws of nature. Eternal laws which Newton, eventually by divine inspiration, had discovered himself. This stage, this absolute referential would be naturally infinite in space as well as in time. In this context, the concept of absolute referential will from then on be one of the fundamental elements upon which classical physics is based and also, implicitly, relativity. In perfect analogy with the concept of absolute referential, others − as many as we like − are conceived as infinite secondary references. These secondary referentials are naturally in true motion relative to the absolute referential and in relative motion with themselves.
>
> Naturally, as you can observe, this attitude – unfortunately very much in vogue – of pretending to know the immutable laws of nature, is nothing more than an infinite arrogance, a sad apanage of many human beings. They naively believe they are the keepers of the truth – not of a sketch, a clue, a part of the truth as it would be expected, but of the ultimate and absolute truth!
>
> By now, an interesting story has occurred to me, which illustrates how vain these human pretensions are about the possibility of the dogmatic and absolute knowledge.

After a pause, Argus asked, "do any of you know the story from the Sufi about the *village of the blind people*?"

Only Iris knew the story, but still joined the others encouraging Argus to retell it.

He resumed:

The Sufis are a mystical group of very remote origins, presently associated with the Muslim culture, who have a very particular way of expressing their ideas through small but significant stories.

This story goes something like this: In times long gone there was a remote village where all its inhabitants were blind. These people lived their life quietly. However, this village had yet another very important and rather rare feature: all the inhabitants appreciated knowledge.

One day they became aware that an elephant would pass near their village. As they had heard vague references to this fabulous animal it was no surprise that they all got very excited! Everyone wanted to 'see' the animal! However, the elephant would pass near the village but not close enough that everyone could go and see it. So, they assembled in council and appointed three of the wisest men among them to go and observe the elephant.

However, as they appreciated scientific knowledge and method, they took care to establish a protocol of observation. So, to avoid any possibility of mutual influence among the observers, they stipulated that each one should make his observation in a perfectly independent manner.

This salutary attitude used by the scientific method is very important. It's mainly aimed at avoiding that an experimental result which was only obtained by a certain research group is taken as a scientific fact. This is so for two main reasons:

1) The researcher or researchers carried out the experiment in good faith but possibly may have been mistaken. A perfectly natural situation that occurs very frequently given the great complexity of experimental systems. In this case, researchers may have made mistakes involuntarily and take one or more artefacts produced by the experimental device as trustworthy results.

2) The other reason corresponds, of course, to the worst of possibilities. In this case, the researcher or the group of researchers involved in the realisation of the experience want, at all costs, to present a certain type of result to justify the large investments

involved in the experiment. In these conditions, as the history of science very well illustrates, they adapt or sometimes go even further by eventually forging the experimental results they want to achieve. From these realities, results this salutary criterion of scientific validation:
For a scientific experiment to be considered trustworthy it must have been carried out in different laboratories and also by independent researchers. It's only when the results obtained by the various sources coincide that the experimental results can then be considered credible.
And so it was! According to the established experimental protocol, the three wise men set out for their mission and each one did the study of the animal in the best way he could. On their return, the whole village got together to hear the wise men talk about the elephant.
The first one, very excited, took the floor and said:
'You cannot imagine how wonderful this animal called elephant is. To tell you the truth, I don't even have words capable of describing such an animal. Just for you to have a rough idea, think for example that the elephant is some kind of snake – very flexible, or even a very thick rope from a ship'.
This wise man had palpated the elephant's trunk.
The second wise man stood up and said aloud:
'You're completely wrong! The elephant is not a snake! Not even a rope! What he most resembles will be, at best, a leaf of cabbage, long and thin.' This man had palpated the elephant's ear.
Totally exalted, the third wise man stands up and says:
'What snake! What cabbage leaf! The elephant is a dignified, noble animal with a rugged appearance in all similar to the strong, sturdy trunk of an oak tree.'
This man had touched the elephant's leg.
All the wise men were right! Partially, we must say, because they only knew a portion of the elephant. Yet they were all deeply deluded when they confused their share of knowledge with reality. The elephant was, without a shadow of a doubt, a much richer and more complex entity than they thought.
Therefore, as I told you, this story seeks to illustrate in a very human way our limitations in the face of such an incommensurable, vast and multifaceted reality.

"This story from the village of the blind is beautiful and instructive", said Amadeus. He added:

> We must always be aware of our blindness. We must be aware that in any historical era the human being is always naturally limited, whether it's by the experimental instruments he has access to or by the mental tools he uses.
> Just to give you a little idea, imagine what biology was before the discovery and use of the microscope. The notions of microorganism, cell and gene, so fundamental in modern biology, were then meaningless.
> That's why I say and repeat: blind are we, always, when faced with the immeasurable wealth and complexity of our Mother Nature!

Argus replied:

> I completely agree with you Amadeus! In fact, to claim possession of the eternal laws, the universal laws that govern, that rule nature, is a true madness. A complete lack of sense of proportions. The best we can aspire to is to be able to establish some principles, as general as possible, that allow us to describe and systematize the information we have in a given historical period. Meanwhile, we must be aware that when conditions change, and the experimental and conceptual universe widens, then possibly the principles set previously will no longer be very adequate to describe what is observed.
> A consequence of this euphoria about the Cartesian method for the resolution of problems, undoubtedly extraordinarily simple and fruitful, was the fact that it was accepted, almost by the entire scientific community, as the true, the one, in short, 'the method'.
> Naturally, as expected, there were some exceptions to this way of thinking. From these we should highlight the great figure of Leibnitz, followed by Huygens, Bernoulli and other researchers linked in general to the physics of waves. The painstaking work made by this sector of thinkers later gave rise to the field theories. However, all these developments were somehow integrated into the prevailing mechanistic paradigm, where, as we know, the simplistic, Cartesian, linear superposition principle reigned omnipresent and omnipotent.
> In any case, even in the so-called non-exact sciences such as sociology, economics and others, where we constantly come across complexity and nonlinearity, this method of perfect Cartesian linear independence was explicitly assumed as the model, 'the method' to

follow. Of course, in the case of these sciences, the result, as we can see, has been at the very least disastrous.
We must also consider that due to the inherent complexity and nonlinearity of natural phenomena, even in the so-called exact sciences, here and there, there were discrepancies in the application of the method. These discrepancies have been somewhat cleverly disguised, concealed by the introduction of supplementary *ad hoc* hypotheses which we know all too well and are suitably called attrition, friction, noise and so on. Thus, by the convenient introduction of these additional hypotheses, the natural complexity of physical phenomena is subject to a forced, or in certain cases, even abusive linearization, I must say in all truth.

At this point Argus paused to take a sip of tea then continued:

It's curious to note that yesterday as today, the human being, possibly due to his fragility and insecurity before the becoming, has always sought to hold to false certainties, to alleged immutable laws that govern nature, anywhere, always and forever. In this particular case, man believed, especially because of the great success of the classical physics, that he had finally discovered the truth, the method, the key that would allow him to have access to all knowledge. Of course, this comfortable attitude of believing that one possesses the truth, more characteristic of the dogmatic or religious way of thinking, goes against the true spirit of science. Science, in its essence, consists of a permanent demand for knowledge, ultimately to attain wisdom.
However, with the advent of the twentieth century, things start to get seriously complicated. This idyllic panorama, where the simplistic method of Cartesian independence reigned omnipresent and omnipotent, begins to show gaps. These difficulties are mainly due to the fact that since the third quarter of the nineteenth century, there has been an incredible advance in the production of scientific instruments.
Just to give you an idea of this enormous progress, it's enough to remember that when Galileo wanted to know if the speed of propagation of light was finite or infinite, he used his finger as a wrist watch to determine the time interval that light took in its path from the observer to a mountain just a few kilometres away and from the mountain back to the observer. Thus, by evaluating the number of pulsations between the emission of the light pulse and its reception

and knowing the distance travelled on the round trip, he could calculate the speed of light.
If we are generous with Galileo we may admit that he could, with this measurement process, estimate time intervals in the range of a tenth of a second. As we now know, light travels at about three hundred thousand kilometres (300,000 km) per second. So, in a tenth of a second the light would travel about thirty thousand kilometres (30,000 km). If Galileo could do the experiment under conditions such that the distance travelled by the light was greater or equal to that distance, thirty thousand kilometres, it was probable that he could eventually measure something.
I want to draw your attention here to the great difficulty he would have in achieving such a feat, since, as we know, the distance from Lisbon to Sydney in Australia is less than 19,000 km.
Thus, since the distance he used was of only a few kilometres, its measurements were, as expected, totally inconclusive.
At the threshold of the twentieth century, as I have mentioned already, due to the great development in the techniques of making scientific instruments, particularly in the field of optics, the interferometer appeared. Interferometers are devices that allow the comparison of the time interval between two complete oscillations of incident waves. As the duration of a full oscillation is what, in scientific language, we call the period of the wave, this extraordinary apparatus allows us to evaluate variations of time that ultimately are fractions of the period of the luminous wave being used. Since the period of the yellow light is in the order of twenty femtoseconds, this means that with these optical instruments it's possible to evaluate time intervals in the order of the femtosecond. A femtosecond being, as we know, equal to 1/1000 000 000 000 000 = 10^{-15}s. If we compare the accuracy of the measurements using the interferometer with those performed by Galileo, which were on the order of the tenth of a second (0.1 = 10^{-1}s), we find that there is an abysmal difference between them.

At this point Amadeus interrupted the conversation by saying "Argus, I don't quite understand how a device, however precise it may be, can measure such small time intervals. More so as we're talking about technology from the late nineteenth century. After all, how do these fantastic gadgets work?"

Fabrus, who was in high spirits said:

Well, Argus, if you'll excuse me, I'd like to explain the operation of the interferometer, because, as you know, I had the opportunity to assemble and use these instruments at the optics classes I gave at the Faculty.
I think that the best thing to do will be to present an apparatus which was simultaneously proposed by two physicists and, as result, bears their names. It's the interferometer of Mach and Zehnder, being that the basic operation of all the interferometers of this type follows a process in every way similar to this.
This apparatus is composed of a stable light source and a set of mirrors supported on a base with a high degree of stability. If the stability of the optical platform, where the mirrors and other optical devices are supported is not good, nothing can be observed due to the tremor of the fringes that appear and disappear in a perfectly random manner. In the drawing I'm going to do, for the sake of simplification, only the mirrors and the light emitting source will be indicated.

And so, aided by Argus, he began to draw the diagram I reproduce below:

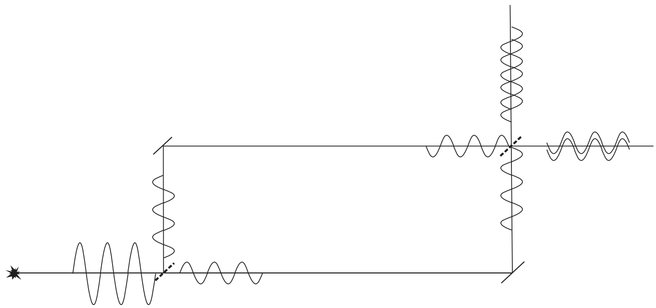

Figure 1-4: Mach-Zehnder interferometer with approximately equal paths.

After drawing the figure, Fabrus continued:

As you can see, the light wave emitted by the source arrives at a half-silvered mirror, represented as dotted lines. As we know, a half-silvered mirror is only partially mirrored so that one part of the light is reflected and the other is transmitted. In this case, the reflection and transmission coefficients are the same. This means that in practice half the light is reflected and the other half is transmitted.

Thus, the wave, the luminous impulse, when reaching the half-silvered mirror is partially reflected and transmitted as shown in the figure. If the upper route is equal to the lower one, after reflecting in two full mirrors, the two impulses arrive at the same time to the second half-silvered mirror as indicated in the figure. In this case, we can see the horizontal waves continue without any deviation and, on the contrary, the vertical waves are in phase opposition. In these circumstances, since the waves are in phase opposition, nothing is observed in the vertical output due to the destructive interference of the waves.
In the horizontal exit the waves are in phase and therefore they will come out reinforced. In conclusion, when the optical path (that is, the path travelled by light) is equal in both paths, nothing can be observed above because all the light exits horizontally. Under these conditions the interferometer behaves simply as a light transmitter.
Suppose now that we're going to increase the optical path of the upper arm of the interferometer with the aid of mirrors, as shown in this figure (Figure 1-5).

He started to draw a new diagram:

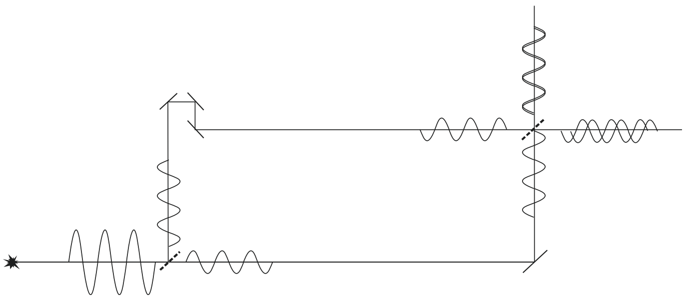

Figure 1-5: Mach-Zehnder interferometer with different paths.

In this case, as you can see, the luminous impulses that follow through the upper path arrive at the second half-silvered mirror with a delay in relation to the ones going on the lower path. This way the waves will overlap at the outputs of the interferometer more or less out of phase depending on the difference between the optical paths.
However, I must say in full truth, that in this type of interferometer, due to the great speed of light the time lag between the two paths is not generally achieved by the process indicated in the figure above,