1-1-2022

Can Physics Attain Its Goals: Extending D'Agostino's Analysis to 21st Century and Beyond

Olga Kosheleva
The University of Texas at El Paso, olgak@utep.edu

Vladik Kreinovich
The University of Texas at El Paso, vladik@utep.edu

Comments:

Technical Report: UTEP-CS-22-07

Can Physics Attain Its Goals: Extending D'Agostino's Analysis to 21st Century and Beyond

Olga Kosheleva[0000-0003-2587-4209] and Vladik Kreinovich[0000-0002-1244-1650]

University of Texas at El Paso, El Paso TX 79968, USA
olgak@utep.edu, vladik@utep.edu

Abstract. In his 2000 seminal book, Silvo D'Agostino provided the detailed overview of the history of ideas underlying 19th and 20th century physics. Now that we are two decades into the 21st century, a natural question is: how can we extend his analysis to the 21st century physics -- and, if possible, beyond, to try to predict how physics will change? To perform this analysis, we go beyond an analysis of what happened and focus more on why paradigm changes happened in the history of physics. To better understand these paradigm changes, we analyze now only what were the main ideas and results of physics, but also on how (and why) the objectives of physics changed with time.

Keywords: History of Physics, Full Cognition, Laplace Determinism, Statistical Determinism, Modern Approach, Unity of Science

1 Introduction

In his 2000 seminal book [3], Silvo D'Agostino provided the detailed overview of the history of ideas underlying 19th and 20th century physics; see, e.g., [4,17]. Now that we are two decades into the 21st century, a natural question is: how can we extend his analysis to the 21st century physics -- and, if possible, beyond, to try to predict how physics will change?

To perform this analysis, we need to go beyond an analysis of what happened and focus more on why paradigm changes happened in the history of physics. To better understand these paradigm changes, we need to analyze now only what were the main ideas and results of physics, but also on how (and why) the objectives of physics changed with time.

In the beginning -- way before the 19th century – physicists believed that the objective of science was full cognition: e.g., Kepler not only described how planets move, he also tried to explain why they are located to given distances from the Sun – and even what will be the fate of a person. This paradigm was replaced by Laplace Determinism, when initial conditions are left to Hokusai and other artists, but, based on these conditions, we can predict their future behavior. Starting with statistical physics – and emphasized by quantum theory -- the new paradigm of Statistical Determinism appeared, when we can only predict probabilities of future events. In many areas of physics, this paradigm is being replaced with what we call Modern Approach, when often we can only predict partial information about the probabilities.

In this essay, following ideas outlined in [5,6,10,11], we explain that this progression of paradigms – and even specific ideas within these paradigms -- was natural: in each case, the main objective of the previous paradigm turned out to be not feasible and thus, a modification was needed. For example, the universal bounds on interaction speed -- introduced by Special Relativity -- naturally comes from the need to reliably predict future events: without such a bound, unknown faraway events in the potentially infinite Universe could affect the future events. This, in turn, explains the ubiquity of differential equations.

Our analysis shows that modern approach also has limitations, and there are already seeds to new idea -- which we call Unity of Science -- when to predict a phenomenon, we need to consider other phenomena as well.

An interesting -- and largely unexplored -- twist is that while historical physics paradigm shifts decrease our ability to predict future events, the corresponding physical phenomena can be used to enhance computations: everyone heard about spectacular promises of quantum computing; we will also overview potential computational use of relativistic effects and of possible future physical paradigms.

2 Full Cognition: the original paradigm

2.1 What is Full Cognition paradigm

One of the main objectives of science is to predict the future -- and one of the main objectives of science and (generally understood) engineering is to find the best way to make this future as good for us as possible.

Often, people object to this description, saying that probably a more important objective of science is to provide understanding of the world phenomena. This is true, but what does it mean "to understand"? How do you check that a person understands calculus? By asking this person to solve problems -- especially problems that go beyond routine exercises. How do you check that a person understands local weather patterns? If this person can, in many cases, successfully predict tomorrow's weather based on today's observations.

In the beginning, people did not know what can be predicted and what cannot be predicted, they did not know what information is needed for such predictions. So the most optimistic viewpoint was that everything can be predicted -- so that, in principle, we can reach full cognition.

This was not just the viewpoint of a few optimists, it was a prevailing paradigm. People went to oracles, people asked prophets, people made future predictions based on the flights of birds and on tea leaves -- and everything was the subject of such predictions: results of future battles, individual histories, etc. People who consulted with the Delphi oracle did not perform any measurements or observations.

This is what kings and princes hired Wise Men for: to give them advice about the future. The famous astronomer Kepler, the first astronomer to discover that the planets follow elliptical orbits, was also routinely asked to predict future fate of different people. This is why people went to their spiritual leaders, to their priests and rabbis -- to seek advice based on the leaders' ability as smart folks to know the future.

While some people continue to seek advice of spiritual seers, in general, this is now treated as a joke. In Russia -- where we come from -- in 1990s, right after the fall of communist dictatorship, there was a popular joke about an airplane designer who consults with a wise rabbi because at high speed, wings keep falling off the plane that he is trying to design. The rabbi without hesitation suggests where exactly to make holes in these wings and -- magic! -- the plane flies perfectly. Why? ask an engineer, expecting to hear that the rabbi consulted with the angels or even with God himself, but the rabbi's explanation is more mundane: during the communist times -- the rabbi explained -- there was Soviet-produced toilet paper where holes were places at exactly these locations, and it would never tear off at these holes, no matter how much you tried.

This is how we view this approach now.

2.2 Limitations of this paradigm

History shows that many of the oracle's predictions turned out to be wrong -- and even predictions that turned out to be correct were often so vague that they could easily be interpreted either way. There is a famous -- probably apocryphal -- example when a mighty king asked an oracle about the future outcome of a war with his equally mighty neighboring king, and the answer was: A great empire will be destroyed. And it was -- except the oracle did not indicate which of the two fighting empires.

2.3 But there were successes

On the other hand, in many cases, when predictions were made not based on supposed divine inspiration but based on observations, and many of these predictions worked well. In many cases, medical doctors were able to correctly predict what will happen to a sick patient, astronomers could predict eclipses, and there were many correct and useful weather predictions as well.

Eventually, people realized that while some predictions are useless, often, predictions based on measurements and observations work well. In other words, they realize that to make a good prediction, they need to first make some observations and/or measurements. This led to a new paradigm.

3 Laplace Determinism: the second paradigm

3.1 What is Laplace Determinism

As we have mentioned, people realized that to make good predictions, you need to first perform as many observations and measurements as possible. So, the optimistic view is that if you perform a sufficient number of observations and measurements, then you will be able to predict all future events.

In other words, if you know the state of the Universe at a given moment of time, then, based on this information, you can predict its state at any future moment of time. This idea – while prevailing for some time -- was first explicitly formulated only reasonably recently, by a 18/19 century French mathematician and physicist Pierre-Simon Laplace. This paradigm is therefore known as Laplace Determinism.

This paradigm is exactly the idea behind Newton's mechanics that we study at school: once we know the initial positions and velocities of all the bodies, we can predict their future positions and velocities. A classical example is celestial mechanics, where we can successfully predict the positions of all the planets centuries ahead, with spectacular accuracy. One of the main discrepancies between the actual planet positions and predictions of Netwon's theory -- resolved later by General Relativity theory -- constitutes 0.43 angular seconds per year, something that only sophisticated telescopes can capture.

This is the main idea behind electrodynamics: once we know the positions, velocities, and charges or all the particles, we can predict what will happen later. This is how most 19 century physical theories work: they were usually formulated in terms of differential equations, so that once we know the initial conditions, we can uniquely predict all future states.

This paradigm is not only about the future -- we can similarly uniquely determine the past, as long as have a sufficient number of measurements and observations. This is the main idea behind the legend of Sherlock Holmes -- that, if a person can observe as many features as possible, all past events can be uniquely reconstructed -- and thus, the Great Detective can solve every crime. And one of the main reasons why Dr. Watson could not do it was that – as Sherlock Holmes mentions in almost every story -- unlike the Great Detective, Dr. Watson did not observe seemingly minor things which turned out to be sometimes important, e.g., how many steps one needs to climb to get to Holmes's study.

3.2 Laplace determinism implies a universal limit on speeds -- i.e., in effect, implies Special Relativity

What we plan to show now is that this paradigm naturally leads to many ideas that, at first glance, seem to be completely independent of this paradigm -- and even revolutionary in comparison with this paradigm. The first such idea is the universal limit on all the speeds -- the idea that was firmly established in physics only after Einstein's special relativity.

Indeed, if there is no limit on speeds, then, to predict what will happen in one second at a current location, we need to know the current state not only at this location, but anywhere at the Universe. Indeed, maybe a very fast body -- which is currently located in a different galaxy -- can come here in one second and change the state at our location? The Universe is large -- according to Newton's understanding, infinitely large -- and we cannot know the initial state at all locations.

So, if we believe -- as people did who believed in this paradigm -- that we can predict the future state of the Universe, this means that there must be a universal limit on all the speeds. In Relativity Theory, this limit is usually described by saying that nothing can be faster than the speed of light, but, fundamentally, it does not have to be the speed of light. For example, it may turn out that photons -- quanta of light -- have rest mass (after all, this may be true for neutrinos, about which people also originally believed that they travel with the speed of light). This would imply their speed is slightly smaller than the upper bound c used in all the formulas of Special Relativity Theory -- but these formulas will not change, the only thing that will change is our interpretation of c as the speed of light.

Please note that here -- and in the following sections -- we do not claim that Special Relativity could be derived simply from the idea of Laplace Determinism: all we claim is that the idea of a universal limit of speed follows from Laplace Determinism. There is a big distance between this simple idea and a sophisticated theory -- just like there is a big distance between the Biblical idea that our world had a beginning (and that in the beginning it was light) and complex formulas of modern cosmology.

3.3 This explains why physics uses differential equations

The universal limit c on all the speeds means that if we want to predict the state at a given location x t seconds into the future, we only need to consider the current state in locations whose distance from x does not exceed c*t -- all other locations simply do not have enough time to affect what we will observe. For example, if we want to predict what will happen on Earth in 1 second, then knowing what astronauts are doing on the Moon will not help -- the distance to the Moon is larger than 300000 km (the distance that light travels in 1 second), so whatever they do will take longer than 1 second to affect us.

In other words, whatever will happen at location x t seconds from now depends only on the state of the small neighborhood of x -- neighborhood of radius c*t. The smaller t, the smaller the neighborhood. So, to find the changes corresponding to infinitesimally small t, we only need to know the values in the infinitesimal vicinity of x. This is exactly what we mean by differential equations: when a change in small vicinity of moment of time is affected only by values of the corresponding quantities in an infinitesimal vicinity of this location.

3.4 Laplace Determinism naturally leads to the notion of fields

How can objects interact? If I place a magnet close to my scissors, they start moving towards it -- why? There is no action-at-a-distance. As we have argued, the motion of the scissors is determined only by the objects in the close vicinity of their location -- and the magnet is not that close. So there must be something that is located close to the scissors and that affect their motion -- and this something is what physicists call a field.

This is how the Sun's gravity affects the Earth -- via a field. So, this notion of a field -- a notion that did not exist in Newton's time -- actually naturally follows from the main idea of Laplace Determinism.

3.5 But why not full cognition?

The absence of full cognition explains why many processes are irreversible while equations of physics are reversible Laplace Determinism is not just saying that we can predict the future if we know the initial state of the word, it also claims that we cannot have full cognition -- and thus, that we cannot describe this initial state of the world by any law.

What does that mean? For example, we can have regular sequences of 0s and 1s, e.g., a sequence 010101... We can also have sequences which are kind of lawless, they cannot be described by a regular law. For example, if we flip a coin and record when we get heads (0) and when we get tails (1), then we will get such a lawless sequence -- and if we get a sequence like 010101... in this flipping experiment, then any observer would say that we were cheating. Such lawless sequences are called random.

In these terms, Laplace Determinism not only claims that we can predict the future based on the initial conditions, it also claims that the initial conditions are, in some sense, random. (Of course, randomness is a vague term: to describe it precisely, we need to specify a probability distribution on the set of all possible initial conditions.)

This sounds trivial, but it has important consequences. Namely, it is a known fact that equations of Newton's mechanics are reversible: if at any given moment of time, we change the direction of each velocity to the opposite one, the system will start moving kind of backwards in time, eventually returning to its initial state. This can be experimentally shown on the example of interacting balls. So, in principle, whatever processes we start with, if we reserve the velocities of all the atoms, we will eventually get back to the original state. In other words, in principle, all physical processes are reversible. (And, by the way, relativity and quantum physics do not change this reversibility of basic equations.)

However, we all know that some physical processes are irreversible. If a cup falls down and breaks, there is no way to make it whole. How can we explain this? This is the "arrow of time" problem that bothered (and continues to bother) philosophically inclined physicists (and physically inclined philosophers) for centuries. What we claim is that the solution -- on the qualitative level -- is simple. Physics is not just about describing the equations, it is also about claiming that initial conditions are random. If we reverse time and start with the future, equations remain the same, but the new "initial conditions" -- which, in the original description, formed the future state -- are no longer random. For example, if we consider the effect of gravity, and we start with the random distribution of matter, then locations with higher density (and thus, higher gravitational field) will attract matter from other locations, and we will see what we see now -- clumps of matter separated by empty space. In other words, what we will see is definitely not a random state anymore.

3.6 Physical ideas that follow from the possibility of feasible predictions: atomism, finite Universe, quantization, symmetries, conservation laws, inequalities (like Second Law of Thermodynamics)

Up to now, we considered ideas that directly follow from Laplace Determinism, ideas without which Laplace Determinism is simply not possible, i.e., without which it is not possible to have algorithms that predict future states.

But, as everyone now knows, there are algorithms and algorithms. Some algorithms are practically feasible, while others are not realistic: e.g., their running time is much larger than the lifetime of the Universe (10-20 billion years). If we have too many inputs -- or if we need to compute too many outputs -- the problem becomes algorithmically intractable. So, the only way to be able to have realistic predictions is to have a realistic number of inputs and a realistic number of outputs in the prediction problem.

In the Laplace Determinism paradigm, to predict the future state, we need to know the values of all the quantities at all the locations at the current moment of time. The more locations there are, the more possible values of each quantity, the more combinations of such values -- the more inputs we have. So, if we believe -- as we do in this paradigm -- that predictions are possible, we conclude that the number of such locations is realistic, that the number of possible values of each quantity is realistic, etc.

In general, realistic means finite. So, we must have at most finitely many locations -- i.e., we cannot have a continuous medium, we must have a finite number of pointwise particles. This conclusion can be split into two parts.

The first part is that in each spatial region, there should be only finitely many particles. This idea -- called atomism – thus follows from the natural assumption that we can have feasible Laplace-Determinism-related prediction algorithms.

The second part is that, since we only have finitely many particles overall, this means that the part of the space where particles are -- and everything else does not make any physical sense, since we cannot observe it -- must be finite. In other words, the Universe must be finite in size. This idea -- seriously explored only with the advent of General Relativity -- thus also naturally follows from the requirement that feasible prediction algorithms are possible.

Similarly, for each quantity, we can only have finitely many different values. This is indeed observed in physics: electric charge cannot be any number, it must be proportional to electron's charge (to be more precise, if we take quarks into account, proportional to 1/3 of electron's charge). For each atom, its energy level can only take discrete set of values, etc. This is what is called quantization and what is now viewed as one of the main features of quantum physics -- but it was actually conjectured and then observed way before quantum physics; quantum physics just provided a quantitative explanation for the observed discrete values. We see that on the qualitative level, the idea of quantization naturally follows from the assumption that there exist feasible prediction algorithms.

Do we need to describe all the values of all the quantities for all the particles? There may still be too many of them, so a natural conclusion is that there is usually some a priori relation between some of these values. A simple example is, e.g., when the initial state is symmetric -- e.g., spherically symmetric. Then, we do not need to describe the values at all possible locations -- for each distance from the center, it is sufficient to describe the values at one single location at this distance -- for all other locations at the same distance from the center, the values are the same. Because of such geometric example, physicists call all such relations symmetries. In this sense, Laplace Determinism naturally leads to the existence of (and need for) symmetries -- which are indeed an important part of modern physics.

Finally, do we need to run complex algorithms -- and prediction algorithms in physics are usually complex and time-consuming – to predict all the future values of all the particles? There may be too many of these future values. It is therefore reasonable to conclude that some of these values -- or at least some combinations of these values -- do not need to be complicatedly computed: for example, these combinations may have the same value as in the previous moment of time. Such combinations are known as conservation laws -- energy conservation law, momentum conservation law, etc. -- and, on the qualitative level, there existence indeed follows from the requirement that feasible prediction algorithms are possible.

For some combinations of values, the previous value does not uniquely determine the future value -- as in conservation laws -- but it should at least restrict possible future values by some appropriate inequality: e.g., the future value should be greater than or equal to the current value. An example of such an inequality is the Second Law of Thermodynamics, according to which the entropy can only increase.

3.7 Limitations of Laplace Determinism

Interestingly, discreteness -- one of the natural conclusions of Laplace Determinism paradigm -- leads to the need to go beyond this paradigm. Let us illustrate this need on the example of a radioactive decay. A radioactive atom, at some moment of time, emits some particle (a photon, an electron, or an alpha-particle: the Helium ion).

According to the Laplace Determinism paradigm, at each moment of time, the current state of the system must be uniquely determined by its current state. But in this case, such uniqueness is not possible. If we start with the state 2 second before the actual decay, then in the following second, the state remains the same, but if we start with the state 1 second before, in 1 second there will be a decay. This means that we sometime cannot predict the future state of the system, even if we know everything about the current state. This impossibility led to a different paradigm.

4 Statistical Determinism: the third paradigm

4.1 What is Statistical Determinism

As we have just mentioned, it turned out that it is not always possible to predict the exact future state. In this sense, in such cases, the future state is unpredictable -- i.e., random. For random predictions, at best, we can predict the probabilities of different future events.

An optimistic viewpoint is -- naturally -- that, if we have a sufficient amount of information about the current state, then we can uniquely determine the probabilities of all possible future states. This viewpoint constitutes what is usually called Statistical Determinism.

This paradigm became prevailing with the advent of quantum physics, where, once we know the current quantum state, Schroedinger's equations indeed enable us to uniquely determine the future quantum state -- and thus, for all future measurements, uniquely determine the probabilities of all possible measurement results.

In this paradigm, the main objective is thus to find the exact form of the equations that describe all the world's physical processes -- what physicists call Theory of Everything. Once such a theory will be found, fundamental physics will, in effect, come to an end -- a glorious end but still end. But will it?

Let us explain what is the problem with this paradigm.

4.2 Fundamental limitations of Statistical Determinism

We started this essay by saying that while the main objective of physics is to predict future events, the main objective of engineering and decision making is to ensure that this future is as beneficial for us as possible. And herein lies a problem.

According to the Statistical Determinism, the probabilities of all future events are pre-determined by the initial state of the Universe: nothing we do will change it. From this viewpoint, engineering makes no sense -- although in reality, its successes are undeniable. Clearly, something is not right with this paradigm.

On a more philosophical level, this can be described as a freedom of will problem: we all know that we can make decisions that make changes in our lives and in lives of others -- and thus, that the future is not uniquely pre-determined, and probabilities of different future states are also not uniquely pre-determined. Of course, we can claim that Statistical Determinism is correct, and freedom of will is an illusion -- but this looks like too unorthodox an approach. We can as well claim that -- like in the movie Matrix -- all our life is an illusion, and in reality, we are harvested by robots. So if we dismiss this weird possibility, then we arrive at a different paradigm, which is reasonable to be called Modern Approach.

5 Modern Approach -- the fourth paradigm

5.1 What is Modern Approach

The main idea of Statistical Determinism was that, once we know the current state of the world, we can uniquely determine the probabilities of all future states. Since this idea contradicts common sense, a natural new idea is that, given the current state of the worlds, we can determine some -- but not all – information about the probabilities of the future states.

This means, in particular, that we cannot have an absolutely correct Theory of Everything: no matter how good is a currently proposed theory, eventually, new observations will surface that are not explained by the current theory, and a new modification will be needed. In this sense, physics is eternal, it will never come to an end. This seems to be, at present, the prevailing view among physicists.

5.2 But aren't we unnecessarily pessimistic?

From one paradigm to another, we are becoming less and less optimistic about the possibility of predictions. At first, in the Full Cognition paradigm, we believed that we can predict everything without even bothering to determine the current state of the world. In the Laplace Determinism paradigm, we still believed that we can predict everything -- although this time, we can only make these predictions after a hard work of measuring the current state in detail. In the Statistical Determinism paradigm, even after all this work, we can only predict probabilities of future events. And in the Modern Approach, we cannot even predict all the probabilities. This looks somewhat pessimistic. What can we do to make the situation better?

To answer this question, let us recall that physics is usually divided into sub-disciplines: cosmology studies Universe as a whole, astrophysics studies stars and galaxies, biophysics studies living creatures, there are solid body physics, atmospheric physics, etc. In each of these sub-disciplines taken on its own, as we go from one paradigm to the next one, we are less and less optimistic about the possibility to predict the future. But good news is that this division into sub-disciplines is somewhat artificial. All of these sub-disciplines describe the same world, the world in which all the processes are interconnected. So while, if we only use facts from each sub-discipline alone, we cannot make good predictions about its object of study, maybe facts and laws from other sub-disciplines will help?

This is exactly what is happening, to the extent that we can consider the resulting emerging state of physics as the new paradigm -- a paradigm that is natural to be called Unity of Science.

6 Unity of Science -- an emerging paradigm

6.1 What is Unity of Science

In a nutshell, it is an attempt to use facts and laws from all parts of physics -- and even from outside physics -- to help predict the probabilities of future events.

6.2 Examples

One of the first examples of using this paradigm was the Anthropic Principle. This example is related to the fact that equations of physics have constants that need to be experimentally determined. Newton's theory of gravitation had the gravitation constant – an empirical constant that describes how strong is the gravitational force between two bodies of unit mass separated by a unit distance. Maxwell's equations -- that describe electromagnetic field -- contain speed of light as an empirical constant, a constant that describes the speed with which electromagnetic waves propagate. Quantum physics contains Planck's constant -- that described how strong are quantum effects. Many other equations contain other constants.

If we change the numerical values of these constants, the world will change. It turns out that even if we change these constants a little bit -- e.g., by 10% -- the world will change so drastically that it will no longer be possible to have life as we know it: either the stars and planets will not be formed at all, or water will become impossible, etc. Thus, the very fact that we have life in the Universe severely restricts the values of the physical constants. One possible explanations -- which is in line with multi-world interpretation of quantum physics -- is that in reality, there are many universes, and we -- the living creatures -- can only exist in those that allow life. Irrespective of the explanation, this is a clear example of how facts and laws from one area of physics helps make predictions in other area.

Another example is how cosmology helps particle physics. A good example is neutrino physics. Neutrinos are notoriously difficult to study, since they practically do not interact with any other particles. Interestingly, we can find upper bounds on their rest mass by the fact that if they had a larger rest mass, the Universe would evolve differently from what we see now.

A completely different example is that quantum models -- when only slightly modified -- explain how people actually make economic decisions [1,2,7,12]. This fits well with the famous general observation by a Nobelist Eugene Wigner that many mathematical theories -- initially developed for a completely different purpose -- are often surprisingly helpful in describing physical phenomena. This is also related to the computer science discovery that all complex computational problems (known as NP-complete) can be reduced to each other, so that any algorithm which helps solve some instances of one of the problems can be -- almost automatically -- used to solve several instances of all other complex problems; see, e.g., [13,16].

This last remark leads us to the final topic of our essay: how all these paradigms affect computations.

7 How different physical paradigms affect computations

At first glance, the effect should be negative. For example, we want computations to always produce the same (correct) results, but if we take into account that in quantum physics, we can only make probabilistic predictions, this makes such deterministic computations difficult -- if not impossible.

Good news is that researchers' ingenuity makes a tasty lemonade out of this sour-lemon situation. Many readers are familiar with successes of quantum computing (see, e.g., [15]), where, e.g., Grover's algorithm allows us to find the desired element in an unsorted n-element array in time proportional to square root of n -- while any non-quantum computer would require, in the worst case, at least n steps. For a database of 1 million elements, this means a thousand times speed-up.

An even more spectacular speed-up is achiever by Shore's algorithm. Once a universal quantum computer is designed, this algorithm will allow us to break all existing codes -- something that now requires astronomically unrealistic computation time -- and thus, will enable us to read all encoded messages in the world.

Similarly, the use of curved space-time can speed up computations [14], effects of special relativity can lead to a square root speed-up [8], and the Modern Approach, according to which no physical theory is final, can help solve almost all instances of NP-complete problems in reasonable time [9].

8 Summarizing

Successes of the 19 century physics were so great and overwhelming that Max Planck, one of the founding fathers of quantum physics, was strongly advised not to go into physics -- since physics at that time was perceived to be almost finished. In spite of these gloomy predictions, 20 century became even more spectacular – with quantum physics and relativity. So spectacular it was, that some people -- even some physicists -- believed that now finally physics is coming to its end, and that anyone interested in great discoveries should move to, e.g., biology.

We hope that this essay -- continuing the analysis [3] of the 19 and 20 century physics performed by Professor D'Agostino -- will convince you that 21 century physics will be no less spectacular than the two previous ones!

Acknowledgments

This work was supported in part by the National Science Foundation grants 1623190 (A Model of Change for Preparing a New Generation for Professional Practice in Computer Science), and HRD-1834620 and HRD-2034030 (CAHSI Includes), and by the AT\&T Fellowship in Information Technology.

It was also supported by the program of the development of the Scientific-Educational Mathematical Center of Volga Federal District No. 075-02-2020-1478, and by a grant from the Hungarian National Research, Development and Innovation Office (NRDI).

The authors are greatly thankful to Prof. Dr. Raffaele Pisano for his encouragement and support.

References

1. Baaquie BE (2004) Quantum Finance: Path Integrals and Hamiltonians for Options and Interest Rates. Cambridge University Press, New York.
2. Busenmeyer JR, Bruza OD (2012) Quantum Models of Cognition and Decision. Cambridge University Press, New York.
3. D'Agostino S (2000) A History of the Ideas of Theoretical Physics: Essays on the Nineteenth and Twentieth Century Physics, Kluwer Academic Publishers, Dordrecht.
4. Feynman R, Leighton R, Sands M (2005) The Feynman Lectures on Physics. Addison Wesley, Boston, Massachusetts.
5. Finkelstein AM, Kreinovich V (1989), Can Science Attains its Goals? Informatika Technical Reports, St. Petersburg, Russia (in Russian)

6. Fox D, Schmidt M, Koshelev M, Kreinovich V, Longpre L, Kuhn J (1998) We must choose the simplest physical theory: Levin-Li-Vitanyi theorem and its potential physical applications. In: Erickson GJ, Rychert JT, Smith CR (eds.). Maximum Entropy and Bayesian Methods, Kluwer, Dordrecht, pp. 238-251.
7. Haven E, Khrennikov A (2013) Quantum Social Science}, Cambridge University Press, Cambridge, UK.
8. Kosheleva O, Kreinovich V (2020) Relativistic effects can be used to achieve a universal square-root (or even faster) computation speedup. In: Blass A, Cegielsky P, Dershowitz N, Droste M, Finkbeiner B (eds.). Fields of Logic and Computation III, Springer, Cham, Switzerland, pp. 179-189.
9. Kosheleva O, Zakharevich M, Kreinovich V (2014) If many physicists are right and no physical theory is perfect, then by using physical observations, we can feasibly solve almost all instances of each NP-complete problem. Mathematical Structures and Modeling 31:4-17.
10. Kreinovich V, Araiza R, Ferret J (2011) Analysis of Information and Computation in Physics Explains Cognitive Paradigms: from Full Cognition to Laplace Determinism to Statistical Determinism to Modern Approach. In: Dodig-Crnkovic G, Burgin M (eds.). Information and Computation, World Scientific, Singapore, pp. 203-223.
11. Kreinovich V, Kosheleva O (2021) Joule's 19th Century Energy Conservation Meta-Law and the 20th Century Physics (Quantum Mechanics and Relativity): 21st Century Analysis. Foundations of Science 26:703-725.
12. Kreinovich V, Kosheleva O (2022) Why quantum techniques are a good first approximation to economic phenomena, and what next. In: Nguyen Hoang Phuong, Kreinovich V (eds.) Biomedical and Other Applications of Soft Computing. Springer, Cham, Switzerland, to appear.
13. Kreinovich V, Lakeyev A, Rohn J, Kahl P (1998) Computational Complexity and Feasibility of Data Processing and Interval Computations. Kluwer, Dordrecht.
14. Morgenstein D, Kreinovich V (1995) Which algorithms are feasible and which are not depends on the geometry of space-time. Geombinatorics 4(3):80-97.
15. Nielsen M, Chuang I (2010) Quantum Computation and Quantum Information. Cambridge University Press, New York.
16. Papadimitriou CH (1994) Computational Complexity. Pearson, Upper Saddle City, New Jersey.
17. Thorne KS, Blandford RD (2017) Modern Classical Physics: Optics, Fluids, Plasmas, Elasticity, Relativity, and Statistical Physics. Princeton University Press, Princeton, New Jersey.