The fairness principle
and the ultimate theory of not everything

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Abstract. I build a "case for noteverything", with 3 levels of analysis. I first contemplate the complementary realms of "faith" and "science" and place the concept of "theory of everything" firmly in the faith category. I then consider how "mindsets of faith" affect scientific work, and compare the vast emptyness produced by the last few decades of the theory-of-everything fashion to the long list of wonderful discoveries produced by the "noteverything mindset", which I illustrate through the examples of Planck's description of blackbody radiation, Einsten-deBroglie wave-particle duality and Fermi's powerful rudimentary theory of weak interactions. Finally I argue, of course less objectively, that even as a choice of faith the "theory of everything" is rather awkward. A natural alternative is faith in a "fairness principle", here proposed as a modern version of a principle first formulated by Kepler, which would imply that our journey of discovery of more and more things will not end or saturate.

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1. motivation and goals

This essay intends to contribute to the debate on the ultimate horizons of science. And let me stress immediately (since this may be viewed as oldfashioned by some readers) that I exclusively characterize as science the journey of search, discovery and description "codified"* by the scientific method. I shall in particular contrast matters of science against products of human intellect that do not follow (or are not formulated fully within the confines of) the scientific method, which I shall simply denominate as "not science" or equivalently "faith".

My main concern here is with the claims that the part of the journey of science which is dearest to me, the one of fundamental physics, might be coming soon to an end. This has been understandably suggested in light of the substantial lack of "progress" (discovery) of the last quarter of a century. And amusingly it has also been argued that the end of fundamental physics should be near for the opposite reason: too much progress might soon be achieved; in fact, many authors expect that we will soon have a "theory of everything", answering all our questions and leaving no further challenges for fundamental-physics research.

I intend to argue here that the end of fundamental physics is nowhere in sight. And that the two main players of the recent standstill of fundamental physics, the lack of new discoveries and the pursuit of a theory of everything, are actually related, at least in as much as the myth of a theory of everything weakened the efforts we directed toward new discoveries.

The easy part of my agenda is the one concerning the theory of everything, a concept whose "scientific emptiness" can be exposed even just using very elementary reasoning, and that can be only of some (and actually not much) interest for those who are inclined to dwell on matters of faith.

But while we can confidently ignore the threat of a theory of everything, there is no logically rigorous deductive way to set aside the concern that our ability to discover more and more things about the fundamental laws of Nature might be approaching a certain level of saturation. I will passionately argue however that this is likely not the case, and advocate a perspective on the history of physics that provides some encouragement for this intuition.

Of some indirect relevance to my analysis is a certain recurring perception of the role of the human race in Nature. A perception according to which the human intellect could rise above Nature, with human-race masters capable of fully "understanding" and dominating intellectually all of the Universe. To the record of this perception we must definitely ascribe the view of physics that was held by many toward the end of the 1800s, when in particular Philipp von Jolly advised a young Max Planck not to go into physics, arguing (in 1874!!!) that in physics "*almost everything is already discovered, and all that remains is to fill a few unimportant holes*". And I find that the view of fundamental physics that appears to be held by many in our times is of similar origin. Our condition is such that it is indeed somewhat natural to end up naively assuming that what we know is all there is, and that "places" (regimes) which we have not yet had access to must host replicas/extrapolations of what we have already seen.

* I shall here assume that the challenge of finding a fully satisfactory characterization of the scientific method (see, *e.g.* Refs. [1, 2]) is inessential to my thesis. One can expect that sharper and sharper formulations of the method will mature as science keeps advancing, and I invite the reader (at least temporarily, in following my thesis) to share my lack of concern toward the apparent tautology of this statement.

Also important for my line of reasoning is the observation that faith in a theory of everything naturally produces a lack of interest toward otherwise rather promising research paths. Using mostly examples drawn from the history of the development of quantum mechanics, I shall instead argue that awareness of the fact that any theory we might ever have should necessarily be viewed as a "theory of not everything" also puts us in the most fruitful mindset, well prepared for profiting from the next little window of opportunity Nature offers.

While most of this essay attempts to provide circumstantial evidence that fundamental physics still has a long road ahead, I reserve my final remarks for some speculative thoughts on whether fundamental-physics research might never end. Rationally it appears that we should consider likely the possibility that at some point, although probably only in a very distant future, there will be a saturation in our ability to discover more and more things. But I find this hypothesis unpleasant and, in an appropriate sense, "unfair". And this inspires me to contemplate possible alternatives, which would provide realizations of a "fairness principle" here proposed as a modern version of a principle first formulated by Kepler.

2. not everything

It is amusing that the expression "theory of everything" has appeared in print so many times, especially over the last few decades, and yet nobody ever fully explained what are the qualities such a theory should have. Even not wanting to look deeply at the weakness of the concept one should at least ask "which everything?". Everything Nature hosts, even beyond what we have so far managed to establish? And how would we know? If at some point in the future a group of physicists (possibly an overwhelming majority of physicists) claims that their theory is the theory of everything should they ask us to stop probing Nature?

A key problem here is that the only claim that can be verified (or falsified) scientifically is the claim that a given theory is consistent with all presently available experimental data. The claim that a certain theory will also be consistent with the outcome of all future measurements that the human race will perform is a possible choice of faith but could never be described [3] as an established scientific fact.

It appears that according to some authors the label "theory of everything" and the assumption that we have reached the end point of fundamental physics should be adopted upon finding a theory that is compatible with all presently-available data and has no free parameters. But, of course, this specific criterion for assuming that the given theory will forever be immmune to further revisions is neither better nor worse than any other criterion, at least from the point of view of science.

Undoubtedly there has been some "reduction" in fundamental physics. Particularly in particle physics we have clearly gone for a while in the direction of fewer particles and somewhat smaller number of parameters (but still ~ 20 parameters!!!). It does appear legitimate to take as (tentative) working assumption that the reductionist programme has not yet come to saturation, but I find it puzzling that some colleagues extrapolate this all the way to the assumption that a theory, if it has to be a "good" theory, should have no free parameters. Perhaps even more amazing is that this no-free-parameter fashion has flourished in spite of the fact that there is no consensus on what it would mean to have a theory with no free parameters. For example, there is a relatively large literature [4] devoted to the case of dimensionful parameters, debating whether some of these parameters truly are free parameters or could essentially be reabsorbed in the system of units of the theory. And it would be also necessary to specify at which level of the theoretical framework the number of parameters should be counted: for example, in a multiverse scenario one could have a fundamental picture without any "externally fixed" parameters but still "our Universe" could only be fully characterized by determining experimentally quite a few parameters.

While these challenges on the counting of parameters are certainly intriguing, my perception is that they are not really providing the core motivation for the popularity of the no-free-parameter idea. I favour the viewpoint that this no-free-parameter assumption is only in part driven by the success of reductionism, while it is for the most part driven by the natural tendency of the human race of finding "reasons" to believe in (have faith in) things that conform to its needs. Other choices of faith have a similar origin. Many find their root in our instinctive aspiration to immortality. In this instance rather than immortality we are seeing a manifestation of the instinctive drive of the human race toward a type of "greatness" that I already briefly described in my opening remarks, when I mentioned the idea of human-race masters capable of fully "understanding" and dominating intellectually all of the Universe. To many of us the idea that we will one day have a theory of everything that perfectly describes exactly how the whole Universe is (even in places/regimes we have no access to) is irresistibly appealing, particularly if there was no free parameter. The appeal here originates mainly from the absence of elements outside our (intellectual) control.

I believe that seeing in science an opportunity to fullfil our instictive aspirations concerning the role of the human race in the Universe amounts to missing a uniquely fascinating opportunity. It seems to me that one can find elements in support of this thesis in Planck's worldview, since he motivated his choice of research in physics by remarking that "*...The outside world is something independent from man, something absolute, and the quest for the laws which apply to this absolute appeared to me as the most sublime scientific pursuit in life.*" Noteworthy keywords here are "outside" and "independent from man": I assume Planck was referring to the fact that the scientific method, also through the discoveries it produces, provides us with a unique opportunity to acquire a worldview that does not conform to our needs, but rather reflects (or better, is constituted by) some objective facts about the Universe. Unless we proceed rigidly within the confines of the scientific method, it is far too easy to end up being convinced that our reasoning is reaching unbiased objective conclusions, when really we are not doing anything else but describe the worldview that is most appealing to us.

While I also would argue that the application of the scientific method to fundamental physics is (in the sense I just described) the "most sublime" activity of which we are capable, it is of course still legitimate to also dwell on matters of faith. But the clarity of any debate will certainly benefit from distinguishing rigidly between contributions that come from the faith side and contributions that come from the science side. Moreover, I here intend to expose some reasons for discomfort toward cases in which faith, specifically faith in a theory of everything, has a particularly strong world-wide influence on the directions of scientific exploration.

3. the noteverything mindset

3.1. the quantum-gravity problem and the theory-of-everything mindset

Our present formulation of the fundamental laws of physics is inapplicable to contexts in which both quantum mechanics and general relativity play a non-negligible role. These contexts are not easily produced in laboratory settings, but the evidence available to us implies for example that quantum mechanics and general relativity both played crucial roles at the big bang. To describe those first instants of the Universe (and possibly many other phenomena we still have no access to) we need formalisms that go beyond a naive combination of quantum mechanics and general relativity.

This "quantum gravity problem" has been studied for several decades [5] without any success (no new phenomena were discovered), and at least in part this may be due to the high value of the energy scale that is characteristic of quantum-gravity phenomena. It appears likely that this characteristic scale will be much higher than the energy scales to which we presently have direct access, possibly somewhere in the neighborhood of the Planck scale ($\sim 10^{28}$ eV). This finds support both in arguments based on extrapolation of the renormalization-group running of nongravitational coupling constants and in arguments based on simple characterizations of the scale at which a description of spacetime geometry in terms of classical geometry breaks down. And if indeed the quantum-gravity realm is so far from the realms we have direct access to related discoveries should be correspondingly hard [6]. But it is legitimate to suspect that at least part of the responsibility for the many decades of failures of quantum-gravity research should be attributed to the enormous influence of the theory-of-everything fashion.

The quantum-gravity problem can be naturally described as a combination of many different challenges [7] for the present formulation of the laws of fundamental physics, but according to the theory-of-everything mindset the only acceptable efforts of development of formalisms to be used in the investigation of the quantum-gravity problem are efforts directed toward a theory that simultaneously solves all of these aspects of the problem. There is a risk here that we might be taking on a challenge that simply is far beyond our strengths. Imagine if Kepler attempted to use his insight on the motion of planets in the solar system* to extrapolate laws applicable all the way down to the distance scales of electronics, quantum physics, and particle physics. Theory-of-everything enthusiasts would have expected Kepler to get the hydrogen-atom spectrum right not by, say, figuring out the ("unacceptably semi-heuristic") Bohr-Somerfeld quantization rule, but rather by figuring out the whole story as we tell it up to now: the states in the Hilbert space, the Uncertainty Principle, the Schroedinger equation and all that. Of course Kepler didn't. But the urge for a theory of everything (whatever that could possibly mean) is so overwhelming that the obvious mismatch between the limited information available to our limited intellectual abilities and the remoteness and

* In contemplating the striking differences between our descriptions of the Earth-Moon system and of the proton-electron system it is worth noticing that the Earth-Moon distance $\sim 4 \cdot 10^{8} m$ is about 10^{19} bigger than the Bohr radius. Presently the shortest distance scales that we reliably describe are of the order of $\sim 10^{-18} m$ which is 10^{17} bigger than the Planck length.

complexity of the quantum-gravity realm was ignored nearly world-wide.

Occasionally advocates of the theory-of-everything approach will justify this state of affairs by claiming that experiments on the ultra-distant Planck-scale realm are impossible and that guidance from the theory-of-everything idea must be used in place of the usual guidance from experiments. But, if experimental investigations of the Planck-scale realm were really impossible of course guidance from the theory-of-everything idea would still not take us to establishing any scientific facts about that realm. Fortunately, it seems that, at least to some extent, the quantum-gravity realm can be probed experimentally. Over the last decade a small community of quantum-gravity phenomenologists has found ways to devise data analyses that provide genuine Planck-scale sensitivity, at least for a few effects that could plausibly characterize the quantum-gravity realm. I have recently reviewed the results of this research effort in Ref. [7], but I do not plan to dwell too much on that in this essay. I shall be satisfied if the reader assumes that experimental probes of the quantum-gravity problem might be possible, and that if however such probes were not possible the quantum-gravity problem should be left to the appetites of those inclined to contemplate matters of faith.

3.2. the development of quantum mechanics and the noteverything mindset

One thing I will stress about the results so far obtained in "Quantum Gravity Phenomenology" is that presently the type of ideas concerning Planck-scale physics that we are finding ways to investigate experimentally can be most robustly derived from certain "quantum gravity theories of not everything" (examples in Ref. [7]), formalisms that are not intended as comprehensive solutions of the quantum-gravity problem, but that could still provide a reasonably accurate description of some aspects of the quantum-gravity realm. Of course this does not sell well with theory-of-everything advocates, but I want to remind my readers of the many occasions in the history of physics in which a mindset of this type proved to be very fruitful.

Well, to get me started on this, let me first note that not only Kepler did not figure out anything about quantum mechanics, but also Planck, Einstein and a few other brilliant minds could not figure out how to get a satisfactory formulation of quantum mechanics for more than 20 years after Planck's break-through description of black-body radiation. They were accessing data exactly at the scales where quantum mechanics is fully manifest but the development of quantum mechanics did not start with the Schroedinger equation: we got to the Schroedinger equation and all that through a long journey built on simple-minded and extremely limited theoretical proposals. Planck's solution of the black-body-radiation problem and Einstein's description of the photoelectric effect were little more than clumsy recipes. And it is striking that, taking as starting point such poor formalizations, not only experimental but also conceptual progress could be achieved, as best illustrated by de Broglie's intuition on wave-particle duality. Clearly the pioneers of the wonderfully ugly "old quantum theory" were not concerned with the "noteverthing" nature of their results. It is fortunate that the theory-of-everything epidemic was evidently still under control at the time, since there could not be a fully developed quantum mechanics without first going through the old quantum theory.

Still discussing quantum mechanics, but looking now at the particle-physics side, similar lessons can be drawn from the history of our descriptions of the weak interactions. The weak interactions should still be viewed as unfinished business, but let us assume that a satisfactory description of the weak interactions matured around 1984, nearly 90 years after the human race stumbled upon the first experimental manifestations (in 1898) of the weak interactions. And the process went through several stages, among which it is useful for me to contemplate briefly the example of Fermi's theory of weak interactions, a field theory of fermions interacting through four-particle vertices. Surely for most theory-of-everything advocates it must seem amazing that so many "true" facts of Nature were uncovered by relying on a theory with such a limited range of phenomenological applicability and limited domain of logico-mathematical consistency. The theory misses completely some key players of weak interactions, the gauge bosons, and as a result also ignores the role of the gauge bosons in the interactions among fermions. And it is not a mathematically consistent theory: it is basically defined perturbatively but the perturbative series is affected by incurable divergences (non-renormalizable). Yet Fermi's theory can be used, with some craftsmanship, to describe and predict several weak-interaction processes. This ugly theory actually was also used to achieve a major conceptual step forward consisting in the realization that, when atoms decay, the decay products should not be viewed* as "pieces of the atom that has broken up". This aspect of Fermi's theory is particularly dear to me, since it shows how a wonderfully ugly theory of not everything, with limited realm of applicability and lacking mathematical rigor, played a key role in changing a fundamental paradigm. Such a limited formal tool proved sufficient to really uncover something qualitatively novel about the "outside world", something unexpected, not particularly desirable, "independent from man".

4. a fairness principle

4.1. not even fun, not even fair

This is all I will offer in this essay in support of my passionate case against the influence of the theory-of-everything myth on fundamental physics. In the closing paragraphs of this essay I will take my "war on the theory of everything" in territory that is unfamiliar to me but that clearly is the territory where the theory-of-everything concept should be perceived as safely at home, which is indeed the territory of faith. Perhaps because of my inexperience with matters of faith I find it surprising that the concept of theory of everything is so popular, and it will perhaps be amusing to share my puzzlement with the reader.

A theory of everything would endow us with God-like powers, masters of the laws of the Universe. I can see that this could appeal to some. But there are aspects of the theory-of-everything concept that are not at all appealing, and I would have expected them to reduce the number of faithful. While the starting point of my thesis was the observation that the idea of a theory of everything is "not even wrong", like all claims that concern the realm of faith, let me now argue that it is also "not even fun". The idea of getting a theory of everything is the idea of the end of fundamental physics. Who could possibly want that? What would we be doing then? How would our condition be bearable without the intrigue of possibly discovering

* Fermi's theory is sufficient to show that the process that "breaks up" an atom may well involve interactions with "in state" given by, say, particles that "were in the atom" and completely different particles in the "out state".

still new phenomena?

And seen from a certain perspective, from these concerns it follows that the theory-of-everything concept is also "not even fair". This is because those left without fundamental-physics research would be primarily the generations that follow the catastrophic discovery of the theory of everything. If, for example, we are the generation destined to discover this wonderful thing, then we at least get to enjoy that final ride.

4.2. the ultimate theory of not everything

Fundamental physics is a relatively young journey of discovery, and when one starts searching for new things of a certain type it is not uncommon to first find many but then eventually, more and more frequently, the ones we find are among the ones we had already found. Not that this means that there are no more new things, but finding things still not in our collection becomes increasingly hard.

While we can confidently ignore the threat of a theory of everything bringing about the end of fundamental physics, I have not much to offer that would allow to set aside the concern that our ability to discover more and more things about the fundamental laws of Nature might eventually reach a certain level of saturation. Rationally I think this is likely, although it should not be a concern for the near future (probably not for, say, a few thousand years). Some contemporary thinkers (even among those immune to the theory-of-everything virus) argue that the end of fundamental physics is clearly in sight, but we can safely assume that they are in a "von Jolly state of mind": I cannot see beyond my nose, there must be nothing beyond my nose. Still I find that reasoning on the ultimate destiny of fundamental physics is very intriguing. Can we at least hope that the journey of discovery of fundamental physics will never reach saturation?

An interesting contribution toward giving strength to this hope could come from mathematics. It would be interesting to provide a toy model of an "ultimate theory of not everything". A scenario I can vaguely describe to illustrate the type of mathematics that could serve this purpose is the one of a toy Universe with logical structure resembling the one of Matryoshka nesting dolls, but an infinite series of nesting dolls and in a multitude of dimensions (amount of energy, amount of complexity, amount of classicality of the apparatus...). From "within" each doll it should only be possible to get information on neighboring dolls, even arriving at the point of fully mastering some of the neighboring dolls, which would then be the starting point for the next step of exploration. I hope a mathematician will soon have (or tell me of the previous existence of) such a toy model for the ultimate theory of not everything, but I have none to offer at present.

Embarassingly, in attempting to provide support for the hope that fundamental physics will never end, I find myself only able to rely on faith. I stumbled upon a sentence attributed to Kepler: "*The diversity of phenomena of nature is so great, and the treasures hidden in the heavens so rich, precisely in order that the human mind shall never be lacking in fresh nourishment.*". From this we infer that Kepler was a great scientist blessed with a certain type of "mystic faith". Even without necessarily sharing Kepler's mystic faith we could embrace the optimistic message Kepler offers. This provides the basis for my "fairness principle", which I do not know how to describe sharply, but basically assumes that every generation of humans will have roughly the same opportunity of being challenged and intrigued by fundamental physics.

Of course this "fairness principle" is neither better nor worse than any other choice of faith, but I encourage especially my youngest readers to embrace it, since I find that it puts us in the best mindset for research in fundamental physics.

5. closing remarks

It is often said that having faith is a blessing, and this in understandable since the ability to believe in what we need to believe is certainly desirable. Those who have faith in the theory of everything are surely blessed. But I have argued here that science is the greatest of our blessings. Forcing Planck (who unfortunately could not complain) to be on my side, I observed that the scientific method can take us on a journey of exploration of an "outside world, independent from man", and no other privilege can be comparable to that.

The idealization of the theory of everything also fits with the system of vaues of our society and our cultures, in which being big and powerful is definitely a positive. But I have here implicitly offered a counterexample: within the Universe we are small and powerless (in many more ways than size and strength could measure) and this is a very privileged condition, at least in as much as it ensures that our journey of exploration of the laws of Nature will be very long and entertaining.

I am fascinated by the idea that this journey might never end. I hope my readers are convinced that it could not possibly end because of the arrival of a magical "theory of everything". But I have stressed that it could end (and probably will end eventually) simply because of an effect of gradual saturation of our ability to uncover new phenomena. In this respect I am blessed for my faith in the "fairness principle", which can comfort me when I end up contemplating the horrifying possibility of the end of fundamental-physics research.
And I feel even more blessed for my faith in the forthcoming discovery of a brand new world, just beyond my nose, safely outside the reach of my brain, wonderfully foreign to everything I have so far imagined or learned to describe.

[1] J. Stachel, *The Manifold of Possibilities*, in *The Creation of Ideas in Physics*, J. Leplin ed.; *Critical Realism: Bhaskar and Wartofsky*, in *Constructivism and Practice: Toward a Historical Epistemology* C. Gould, ed.

[2] I. Lakatos and P. Feyerabend, *For and Against Method: Including Lakatos's Lectures on Scientific Method and the Lakatos-Feyerabend Correspondence*, M. Motterlini ed.

[3] This point about "testing" the hypothesis that a certain theory is a theory of everything is a particularly pathological example of "Underdetermination of Scientific Theory", a concept for which readers can consult plato.stanford.edu/entries/scientific-underdetermination/ and references therein.

[4] M. J. Duff, L. B. Okun, G. Veneziano, *Trialogue on the number of fundamental constants*, arxiv.org/abs/physics/0110060.

[5] J. Stachel, *Early History of Quantum Gravity*, in *Black Holes, Gravitational Radiation and the Universe*, B.R. Iyer, B. Bhawal eds.

[6] G. Amelino-Camelia, *Quantum theory's last challenge*, arxiv.org/abs/gr-qc/0012049, Nature 408 (2000) 661-664.

[7] G. Amelino-Camelia, *Quantum Gravity Phenomenology*, arxiv.org/abs/0806.0339

I am indebted to John Stachel and Cecilia Voena, for several valuable comments on an early draft, and to Giulia Gubitosi and Flavio Mercati, for reading a nearly-final draft and offering some valuable comments.