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Research Article

A Heuristic Sketch of How It Could All Fit Together with Time

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On a scientific meta-level, it is discussed how an overall understanding of the physical universe can be built on the basis of well-proven theories, observations, and recent experiments. In the light of almost a century of struggle to make (common) sense of Quantum Mechanics and to reconcile it with General Relativity, it is proposed to (for some time) forget about quantizing gravity or striving for one Theory of Everything or "Weltformel", which would describe the whole of reality seamlessly without any joints or suture marks. Instead of one single monolithic formalism, a three-legged compound approach is argued for. Quantum Mechanics, Relativity, and Thermodynamics are proposed as the main pillars of reality, each with its well-defined realm, specific features, and clearly marked interfaces between the three of them. Not only classical reality, which is rather directly accessible to us, is then comprehensively modelled by their encompassing combination. Quantum phenomena are understood as undoubtedly lying at the bottom of classical physics and at the same time, they become "fully real" only when embedded in classical frames, i.e., preparation and measurements in time. It is then that thermodynamics steps in and provides the mediating glue as it does at interfaces towards gravity. Decoherence is understood as a smooth way of gradually transferring information and basically dumping entropy to a suitable environment. The aim of this short contribution is not to deliver novel quantitative results but rather to propose a comprehensive research program and to coarsely lay out a very roughly coherent sketch starting from the beginning of the one universe, which we inhabit. The all-embracing picture is claimed to be one of ("mutually induced") emergence.

1. Introduction

Since the dawn of science, and certainly long before, humans have wanted to know how the universe came about and how it is structured and working in a grand view, how it could fit all together. With

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myths and answers offered by religions ever more losing their convincing power, this remains an unsolved scientific question. The currently best available physical theories do not yet yield a unified or commonly agreed account. Here, an attempt is made to sketch an overarching picture of all of physical reality. The perspective in this short paper deliberately is a very wide one, and the layout of the contribution is meant to somehow reflect its message: the physical universe is identified as a braided self-referring structure, time as one pillar itself emerging only in mutual dependencies just like the other building blocks of our understanding. Physical laws, as well as constituents and forces, consequentially are best understood as abstractions, with clear-cut if --> then relations valid in limited contexts. Additional motivation for the chosen approach will become clearer towards the end of this tiny paper.

Arguments about how to understand and interpret Quantum Mechanics as one fundamental well-proven pillar are as old as the first conceptualizations of the mathematical framework itself. As a second foundation, Special and General Relativity, although markedly distinct from everyday direct human experience, appear somewhat easier to grasp. Given the paramount success of each theory in its field of application, usually many orders of magnitude apart, the very best minds have toiled for more than 100 years to somehow reconcile quantum mechanics with relativity, alas, hitherto without resounding success. Thermodynamics provides another cornerstone. In its essence, it is more an abstract and, in a sense, eternal mathematical theory. According to the frequently cited assessment by Albert Einstein, thermodynamics uniquely constitutes one foundation of our understanding of the world, which will within the framework of the applicability of its basic concepts not be overthrown by new findings.

Here, it is humbly suggested to take a big step back and assume a very broad perspective for a fresh look, keeping for a start to a very coarse and superficial level while exploring what a rather sketchy but all-embracing picture comprising quantum mechanics, classical physics, relativity, and thermodynamics could look like while staying firmly anchored in solid science.

With more or less obvious paths leading to no true breakthrough in unifying our currently best understanding of the universe, some apparently outlandish inspirations seem appropriate. In line with a recent account of cognition, it shall be tried to sketch a big schematic picture before details are worked out in necessary subsequent steps[1]. There is no doubt that at the end, well-matching quantitative accounts, “laws,” are the goal. It should just be avoided that these (the difficulties finding them) block or blur an overall view and thus hamper progress from the onset.

The aim of this paper is to assess a possible truly overarching match between currently available experimental/observational evidence and fundamental theoretical findings; it is structured in the following way: chapter 2 looks back at the very roots of interpreting quantum mechanics and argues for a well-defined Heisenberg cut. On that basis, chapters 3 and 4 investigate causality and the measurement of time with real clocks and its progression in one sense only (the arrow of time). Subsequently, baselining time as emergent, it is suggested in chapter 5 that a variable "progression of time" might resolve some of the problems which had provoked the conjecture of an initial inflationary phase. The focus is further shifted to the character and role of gravity in chapters 6 and 7. In the light of the previous sections, it is then argued in chapters 8 and 9 that neither dark matter nor dark energy nor many worlds appear required for a consistent overall picture of the physical universe. Principal limits to achieving any full understanding are dealt with in chapter 10, while the conclusions in chapter 11 try to outline an overall self-reflective and -consistent narrative and propose some immediate upshots of the presented considerations.

2. Timeless Quantum World

From the very beginning of quantum physics, Niels Bohr emphasized the importance of the involved classical experimental apparatus. Quantum effects are always described and observed in a context in the real world[2]. On the coarsest "outside" level, the relevant context is classical; it frames free and undisturbed quantum states at a beginning event as well as at an endpoint. The latter ones we are usually well aware of when we record and report them. Definite measurements yield irreversible classical results, but any selected quantum state also needs some preparation harnessing classical boundary conditions[3][4]. Our everyday world is profoundly classical, and we know of ("weird") quantum phenomena only from more detached constellations and deliberately arranged experiments. Exotic behaviors of quantum systems like entanglement and superposition of states are very fragile and occur almost exclusively in carefully controlled closed set-ups and for limited time intervals, well-shielded from any disturbing influence from an outside environment[5]. It can be shown that relying fully on quantum systems also for reference, i.e., quantum reference frames (QRFs), superposition and entanglement are relational and in fact just different sides of the same coin[6]. Inside, quantum theory does not distinguish between prediction and retrodiction, the Born rule applies equally well in both directions of time[4].

In Wigner's friend scenarios, a memory of the friend would, in general, be reset by Wigner's measurement, which would conflict with the no-signaling condition[7]. Interfaces between quantum and classical phenomena are marked with time stamps, i.e., in most cases, some type of persistent classical memory. This need not be a record set in stone; fleeting ("pale") traces suffice[8]. After some while, probably nothing more than a minute increase in overall entropy is left, while some free energy has been "consumed". Importantly, at every irreversible transition (like erasure, i.e., when the input state cannot be fully recovered from an output state), there is a concomitant change, i.e., an increment, in entropy in some environment outside of the narrow (quantum) system under investigation[9][10][11]. Entropy characterizes uncertainty and ignorance. After an event with a growth in entropy, it is not possible to reconstruct what had been the exact and complete state before.

It has recently been proposed that a clear Heisenberg cut can be identified with an increase of entropy and the associated transfer of energy (or "consuming" another conserved quantity) between the investigated system and its environment according to Landauer's principle[12]:

$$\Delta \mathrm{E} \geq \mathrm{kT}\ \ln 2$$

Unitary quantum systems inside their classical demarcations could then be conceptualized as "timeless". This condition provides all the internal opportunities for the exploration of each and every development, which is permitted by the boundary conditions, in parallel. All available options are taken into account as with Richard Feynman´s path integrals[13]. As long as nothing irreversible occurs, all possible states will somehow potentially/ghostly co-"exist" inside an isolated QM system according to the Schrödinger equation "at the same no-time", with their respective probabilities for being observed given by the Born rule.

For the arguments here, it can be disregarded that there is, in fact, a whole "zoo" of different but related definitions of entropy in different (quantum) contexts[14][15][16][17]; basic Boltzmann entropy suffices for a start.

It can convincingly be argued that there is no way of getting time from no-time in quantum mechanics without first presupposing some concept of time[18]. The Hamiltonian operator, corresponding to the total energy of a system, is firmly rooted in classical reality, and it generates the time evolution of quantum states in the Schrödinger picture, in fact by defining boundary conditions possibly varying with respect to laboratory-time. For observables, speed limits apply[19]. Dynamical quantum systems are thus tightly tied to laboratory "standard" time during unitary evolution, while internally enjoying all the freedom also in their phasing such that only statistical predictions are possible before a (collapsing) measurement. In case external classical boundary conditions vary with time explicitly, the last version (defined by the Hamiltonian and by the associated classical time stamp) is decisive. Unintended disturbances interrupt the unitary evolution the same as for any static system as soon as enough energy is transferred / entropy produced.

Upon the collapse of the wavefunction, linearity and unitarity are broken, and one classical outcome is materialized depending on the overall set-up, the apparatus; e.g., wave- or particle-behavior is observed[20]. This holds for single individual cases ideally. The Landauer threshold is somewhat paradoxically strictly applicable in this simple form only in quasi-static conditions; the picture is more complicated when unavoidable fluctuations are taken into account, but Landauer´s principle is also valid then[11][21].

With multiple systems / repetitions, statistics can be compiled, and in an intricate set-up, a quantitative complementarity relation for wave-particle behaviors has been measured[22]. It is hypothesized that weak measurements employing an ancilla disturb / collapse the system of interest only partly and for each data point effectively transfer just a tiny amount of entropy / energy; no sudden collapse ensues, but entropy will accumulate gradually. Tsallis entropy might be an apt tool to describe this[17]. Dilution of entanglement in the environment, i.e., decoherence, leads basically to the same classical behavior of a considered system. A trade-off between information gain, reversibility, and disturbance has been demonstrated for quantum measurements employing ensembles[23]. The more information is extracted, the more a state is disturbed and/or the less recoverable it is, all for a constant space frame. There is a minimum amount of entropy production required for obtaining information about work done to a quantum system driven far from equilibrium[24]. Entropic uncertainty relations can be shown to be equivalent to wave-particle duality[25][26].

Contextuality denotes the fact that measurements of quantum observables can in no case be simply thought of as revealing pre-existing values[27][28]. Results depend on which other observables are measured together in a sequence. Projective measurements are not commutative; they in turn yield (new) classical results and constraints, and their order matters. Surplus weirdness can be avoided when carefully keeping to the respectively applicable contexts[29][12][30].

Normally, we do not exactly know the complete frame. A single photon without a heralding companion does not tell whether or how there exist(s) any entangled state(s); this is the Holevo bound.

It appears not immediately clear that at the start of an (internally) timeless phase, a similar discrete event has to happen for properly conditionalizing an thereafter isolated individual quantum system. The necessity of carefully preparing a quantum state has been described by Niels Bohr, Willis Eugene Lamb, John Archibald Wheeler, Andrei Khrennikov, and many others. Given that quantum theory is time-symmetric, it only seems natural that the beginning and the end of a completely isolated quantum system are considered equivalent (except for their embedding in outside (laboratory) time).

Current conceptualizations of Bell measurements emphasize their contextuality aspects[31][32][33]. Experiments with photons from a distant star or quasar might raise some doubt but fit nicely with the idea that the undisturbed travelling photons are somehow "out of time" and fully enter reality only upon registration. Light quanta are not detected as arriving in earmarked entangled pairs; such "fossile" light can effectively be used as a random generator for closing the freedom-of-choice loophole in Bell experiments[34]. The latter only if one does not believe in principally untestable metaphysical superdeterminism, which claims that about everything is somehow correlated or determined since the very beginning of the universe.

3. Clocks in the real world

The classical frames of quantum systems with their start- and end-points can, depending on the available details, be ordered in at least one way to form consistent histories. Time thus starts out locally and discretely. Events with their records have been described as creating empirical (space-) time before[35][36].

Not only collapse events, but, of course, also interactions in the classical domain with energy transfer (and entropy production) generate records and timestamps. Given some energy/time uncertainty relation, "moments" come with a fuzzy extension, i.e., minimum duration. The sheer number of related and partly overlapping and also nested/embedded systems following the same laws and producing records allows for their qualified ordering and, depending on the context, also synchronization; practically, quantitative, smooth, and continuous time emerges. Employing a model of a relaxation process, time can be shown to appear as a coarse-grained parameter in the statistics of measurements of events very similar to temperature[37].

Any clock produces entropy, and clocks need energy; the better they are, the more. The laws of thermodynamics dictate a trade-off between the amount of heat dissipated (entropy produced) on one hand and the accuracy and resolution on the other[38][39][40].

Boundary conditions are given by relativity; time stamps are relative in a context, and they are local. The dependence of outcomes on the order of such events establishes one direction of time (in a context/history), which cannot simply be reversed. This is ascribed to the entropy generated when establishing the records. These traces, together with the mechanism generating them, effectively constitute clocks, which cannot exist as such inside an isolated timeless quantum system. Any clock needs something that changes, either periodically or as in some form of relaxation. The expansion of the universe is a special and most important example of the latter because all other clocks are one way or the other anchored to that universal reference[41].

The well-known Page Wootters mechanism for supplying clocks to a quantum system involves a second system in which memories/records are conserved (i.e., effectively classical in disguise)[42]. Even disregarding a full collapse of a quantum system, energy cannot be measured arbitrarily fast by an external system, and the evolution observed by an internal clock cannot be unitary during an energy measurement, regardless of whether an internal or an external system carries out the measurement[43].

In general, quantum measurements cannot be performed instantaneously in decoherence-focused interpretations; the time required scales with the change of entropy of the measured system[44]. There are speed limits on observables both classically and for quantum systems[19]. Also, in light of what has been shown for (continuous) position, it seems natural to state that time principally cannot be measured to arbitrary precision[45]. Measurements have a minimum energy cost; infinitely exact measurements quite generally would require unbounded resources[40][46].

No clock is a clock without memory[12]. Clocks with some permanence require some entropy production; if they were all unitary and reversible, there would be the risk that they run in the wrong direction[47]. A definite thermodynamic time's arrow is restored by even a quantum measurement of entropy production[48]. In experiments purportedly putting counter-running arrows of time in a superposition, (only) the order of unitary evolution steps was affected, and no record with entropy was generated during the process before the very (classical) end.

For periodic clocks, progressive counting is essential, and for aperiodic ones, it is required to remember at least some starting value. Real physical clocks cannot be in equilibrium, and they cannot be reversible; they require some reservoir of low entropy or some source of free energy. In suitably large enough real classical systems, memories, at least traces, are possible, and entropy is never decreasing; reversibility is barred, and causality can be relied on[49][50].

Building on the embedding of quantum processes in classical spacetime, it can be shown that processes with indefinite causal order (ICO) are forbidden unless input and output agent systems are nonlocalized[51][52][53]. Even then, one can "zoom in" and unveil a finer level of description exhibiting a well-defined and acyclic causal order. ICO processes, which violate causal order, cannot be realized faithfully in classical spacetime.

Causality is a time-oriented abstraction on the basis of (interaction) events, in particular their observed order, and correlations relatively high up in a hierarchy of concepts following an ontology as devised by Nicolai Hartmann[54]. Human cognition unfolds in time, and it works with expectations, but not in the sense that we only dream up and thus constitute regularities, but rather that these are (often statistically) extracted from learning, in part already ground-laid by evolution over eons, as sketched in the Ouroboros Model[1]. Linking two events causally demands much more connection(s) between these two than mere succession in time; i.e., generally, the impact of an event or intervention has to be described[36][55]. To understand anything acceptably, detailed schemata have to be activated and filled without leaving big gaps between any purported cause and effect. This, in turn, does not mean that clocks would require some observer to read them or that cause and effect would wait for anyone to disentangle them.

Here it is argued that one has to forego any tacit assumption that normal classical laboratory time can be directly extrapolated to arbitrary settings, e.g., like the very beginning of the universe.

4. The Arrow of Time

Ordered records with reversible transitions in forward and in backward direction do not suffice for keeping time, nor for establishing a well-defined and univocal direction of time passing. A most simple example is given by an old film roll, which (given suitable content) can be seen with one or the other succession of frames without noticing any uncertainty or error. Similarly, it is currently agreed knowledge that the standard microscopic laws of physics, which describe possible developments in forward direction, do this equally well in backward direction[48].

Common agreement can be refined and superseded as a result of more information (from additional sources like, e.g., more powerful instruments) becoming available, which can yield a new and improved understanding. Recently, it has been shown that, indeed, there is a microscopic classical phenomenon that unambiguously specifies an allowed forward direction of time. An accelerating wave equation is reported to have a solution only with time progressing but not in reverse[56][57]. The long-standing Abraham-Minkowski controversy about the speed and momentum of light in a changing medium has thus been resolved by carefully considering the used frames of reference; i.e., the discussed discrepancies can be ascribed to non-local observations. In terms of longitudinally accelerating waves, there is thus a well-defined direction of time, an "arrow of time." Relativistic (observer-dependent) effects ensure the conservation of momentum of the wave between different media. The proper time of the accelerating wave is universal and analogous to the proper time in Special and General Relativity, not necessarily the same as laboratory time. With a constant reference velocity, momentum and energy are conserved for a wave moving along a geodesic.

Time dilatation, as described by Special Relativity, ensures a smooth interface to the timeless quantum realm: in a system speeding up and approaching the speed of light (thus also becoming ever more isolated), internal time drags on ever more slowly, and its passing diminishes, coming to a standstill in the limit (for an outside observer). In a recent paper, it has been shown that even tachyons, by definition travelling with a speed larger than the speed of light, can consistently be fit into standard covariant quantum field theory, just that the phase space has to be doubled[58]. Taking the initial and final state of the system on equal footing as boundary conditions for the calculation of probabilities involving tachyons makes the theory mathematically consistent. It is highlighted by the authors that this endorses the two-state formalism of quantum mechanics featuring the time symmetry of quantum measurement processes proposed 60 years ago[59]. A time-symmetric theory then obtains the arrow of time by macroscopic factors like an embedding in the expanding universe.

Since its first conception by Arthur Stanley Eddington, the arrow of time, which we experience in the macroscopic world, has been traced to a state of very low entropy at the beginning of the universe. Its continuous expansion goes hand in hand and delivers a backdrop with time progressing in only the forward direction[41]. With progressing time, the universe develops towards some equilibrium, and entropy is increasing. This might go on until the universe has so much expanded that almost any finite region is empty; this would then be an effectively timeless condition with zero entropy (after some maximum in between).

While there is little disagreement about the principal existence of a postulated highly ordered state with low entropy in the early universe, it is not so clear how this purportedly very special state could ever have arisen. As to time then, it would progress very slowly due to the dilatation caused by the enormous mass concentration and possibly also resulting from the dilation as a consequence of very rapid expansion (all for later outside observers where possible). Leaving out for now the very first moments, there is an obvious way to pinpoint an important transition in time at decoupling when the universe was about

300,000 years old and approximately 3,000 K hot, with expansion going on thereafter. This is documented in the cosmic microwave background, CMB[60].

The proposal is, again, to consider the full frame of reference, in particular its change from one condition to another in the early expanding universe. What was an average high entropy state of matter at an early point with basically only short-range forces became one of very low entropy triggered by the changing balance between the contributions of the dominating forces. Gravity at that time of continued expansion becomes the most effective force on larger scales, and it is attractive. As gravity tends to clump matter together, a homogenous smooth state of high entropy turns into a highly improbable state of low entropy[61]. Roger Penrose, with his Conformal Cyclic Cosmology, for example, has raised similar arguments (in order to bypass questions relating to special initial conditions, hypothesizing an eternal recurrent universe)[62].

Deemphasizing the role of gravity, another special point in time has been proposed by Carlo Rovelli[8]. At about “one second” after the Big Bang, protons and neutrons were no longer in thermal equilibrium due to the expansion of the universe. At the freeze-out temperature of 0.7 MeV, the ratio between helium and hydrogen was fixed. Giant clouds of hydrogen can later be identified as providing one suitable reservoir of low entropy[63].

Very recent calculations arrive at the conclusion that the universe, at its current state with low entropy and a small cosmological constant, may actually not be so special anyway[64]. Even if coarse graining is required for defining entropy, this does not necessarily mean that the arrow of time turns fully perspectival and could only be rescued with some type of anthropic argument.

The Bekenstein bound specifies an upper limit on how much entropy can be contained in a volume with a given energy (on the surface) following the second law of thermodynamics[65]. A small baby universe would have its limits. As soon as there is an environment to which enough entropy can be dumped, quantum states can be framed (classically), and matter can turn into real; the expansion process at least then becomes irreversible. It has been argued that time dilation itself (both from Special Relativity and gravitational causes) produces entropy[66]. For the early constituents of the Big Bang, which fly rapidly apart, time dilation would have applied, with the expansion generating entropy (and time).

Each single photon of the CMB detected now has lost most of its energy since it was emitted, redshifted due to the expansion of the universe. Propagating all the time with the speed of light, these photons cannot really be called “tired,” but they are definitively “stretched.” Here, it is hypothesized that the “lost” energy went into entropy production, again adhering to Landauer's principle. The ratio between energy and entropy thus changes during expansion, which fits with a corresponding increase of the Bekenstein bound[65].

The expanding universe in total can be seen as an "absorber," allowing only outward-spreading electromagnetic waves. The microscopic direction of time from the accelerating wave equation thus fits nicely with the general cosmological arrow of time, and so do all other such arrows, e.g., our perceptual and psychological ones, too. Animals, including humans, actually are (inter alia) clocks employing, in fact, a plentitude of mechanisms in parallel, which might be one reason why a timeless quantum world is so hard to imagine and is felt to be so weird. Interestingly, Large Language Models, which are the current most successful models of human thought, are slightly better at predicting what comes next in a sentence than what came before[67].

5. No need for inflation

In standard scenarios of the Big Bang, time and gravity, and actually all of the world, start in a state at least close to a mathematical infinity. Inflation during a first short period then is purported to finally yield a universe that matches current observations.

The classical preparation of an isolated quantum system poses a challenge in any laboratory. With gravity probably assuming no decisive role long before freeze-out or recombination and transparency, quantum effects of the other three fundamental forces of nature dominated. The very beginnings of the universe certainly were not classical, and the conditions of systems separation, thermodynamic imbalance, and long thermalization times for memory and traces very probably were not met[8]. Far from equilibrium, with time only emerging in the process and diverse non-linear feedback between all constituents, certainly no nice linear scale for the development of anything can be expected.

The proposal here is to consider the possibility that time in some way progressed from a very beginning, but clocks ticked differently before the advent of hadrons and/or neutral atoms, which could provide some basis for defined (classical) boundary conditions and a suitable environment for records and for dumping entropy. The idea is trivial: something can seem extremely fast in case the available clock runs very slow. Not some intrinsic speed, but rather the applicable frame and scale would be to investigate for answering open questions, e.g., concerning smoothness. A "slow genesis" of space and time during that initial phase might, in hindsight, just look like “inflation” (with its “timely duration” constrained also by some sort of time/energy uncertainty relation).

Presumably, the Hubble tension could be addressed by allowing time to pass differently in very early and later phases of the unfolding expanding universe, similar in effect to changing coupling constants. Probably, this is not really needed, and identifying some other biases in measurements can resolve the currently observed discrepancies between diverse methods[68][69]. At the time the cosmological microwave background froze out, the transition most likely was not razor-sharp, and remainders of earlier “slower time” might have still been effective (the universe appears to be expanding faster in our (local and temporal) vicinity). This might just match with (almost) no time passing before decoupling (given ample opportunities for all types of development like in small isolated quantum systems). The time passing close to the center of the young expanding universe would have been gravitationally dilated compared to more peripheral volumes experiencing a weaker gravitational potential, and expansion speed (probably higher at the periphery) could have had an influence, too (probably even a compensating one). Baryonic acoustic oscillation features observed in the CMB now could be blurred due to possibly associated gradients.

Inflation has been proposed to solve a number of problems, like the observed homogeneity of the visible universe in every direction[70]. After tremendous initial success, foremost earlier proponents have turned fierce skeptics. Discrepancies between ever more exact measurements have surfaced, and it seems that in order to avoid extreme finetuning for certain parameters, others have to lie in unbelievable narrow regions[62][71].

A deep arrow of time pointing in the usual direction but with “less speed” might obviate the need for an inflationary phase. Homogeneity does not always require direct interaction. The behavior of the constituents according to the same laws, which became effective after wider separation, could have led to very similar outcomes overall. With one common timescale for all phenomena ascribed to the first moments after the Big Bang, it can be speculated that changing just that scaling has only moderate impact on specific mechanisms unfolding. With space expanding, unitarity breaks down even without disturbance, and only isometry appears to be left[72][73].

6. Matter and antimatter

While gravity might not be of top importance directly for the progressing of time in the earliest phases, it might be interesting to note that within the initial gigantic concentration of energy/mass (even if not infinite), conditions will vary to some extent. This is hardly seen today, one main reason why an inflationary period was invented originally.

Gravity defines geometry, and there has to be some initial difference whether particles are located at the middle of the baby universe or at its periphery. Some type of gradient appears unavoidable. Even in a constant gravity field, the temperature in a gas in thermal equilibrium and in gravitational equilibrium cannot be uniform[74]. In this case, still, a uniform temperature is seen by an observer due to gravitational redshift. Given the universality of free fall, the validity of the Stefan–Boltzmann law is not affected by a temperature gradient stemming from gravity[75]. The Tolman–Ehrenfest effect probably canceled (almost all) imbalance in the CMB measured today.

If gravity affected matter and antimatter slightly differently, this might be the reason for the absence of antimatter in the observable universe. First measurements of the behavior of antimatter in the weak gravitational field of the Earth show no difference from ordinary matter but need not be of real relevance for very high concentrations of energy and gravity. A recent experiment at CERN most probably was far too insensitive to see any difference in gravitation for matter and antimatter at a level likely required to explain the imbalance observed in the universe today[76]. Actually, it is not so obvious how any finding in such an experiment would relate to a minuscule asymmetry during baryogenesis[77].

Some tiny violation of the CPT symmetry could explain the dominating prevalence of matter over antimatter[78][79]. Charge and parity appear pretty quantized and solid. This is different for time. Here it is suggested that, in fact, time-symmetry is the crucial component, and it is violated in the relevant context far away from equilibrium. With time itself only emerging during the violent processes of expansion and baryogenesis, it certainly cannot in this epoch be considered as an effectively “static container” in which any development can run unaffectedly in forward or backward direction equal in all detail. To a much lesser extent, this applies in general: already Heraclitus knew that no one can step into the same river two times.

7. Gravity from thermodynamics and the other way round

Gravity, in turn, might also be seen as emergent as an entropic force. Ted Jacobson has shown that the Einstein field equations, which describe relativistic gravitation, can be derived by combining general thermodynamic considerations with the equivalence principle (involving the Bekenstein bound)[65][80]. Erik Verlinde and others have investigated how alternative proposals for gravity might originate in entropic scenarios[81][82]. Jacob Bekenstein has also proposed a generalized second law, which is valid when the Einstein Equation holds, linking the latter to vacuum entanglement[83][84]. In a program aimed at deriving gravity from quantum mechanics and utilizing several mostly reasonable assumptions, the emergence of spacetime from entanglement, i.e., "bulk entanglement gravity", has been sketched[85].

If it is most difficult to reconcile gravity and quantum physics at the beginning of time, it could be interesting to look at the other side, to the end of time. With expansion going on forever (let us assume), maybe even accelerating for some of the time, the universe turns basically into an empty void. Still, gravity might not peter out incessantly and drop to perfect (mathematical) zero. Time itself would freeze, and with it, some bottom value of gravity. In addition, the very act of measuring would require some means, i.e., some type of apparatus, which cannot completely be devoid of mass or energy. This, in turn, would produce gravity, albeit very weak. At least some inevitably self-induced gravity thus will always be present for any observer[40]. This would be another analogy to thermodynamics, i.e., to the third law, saying that absolute zero cannot be achieved in finite time.

It is proposed to see gravity not smoothly dropping to zero in the weak limit as one argument for some type of modified Newton/Einstein gravity, MOND. Modified Newtonian gravity has recently booked some success in various versions; indefinitely flat rotation curves of spiral galaxies[86][87][88], gravitationally weakly coupled binary star systems[89][90], the cosmic microwave background[91], and the observed bulk flow[92] can be described/explained.

To account for gravitational lensing, earlier versions of MOND need to be generalized and made relativistic. Maybe, in the end, matters are more complicated, and some tensor-vector-scalar theory, as proposed by Jacob Bekenstein, is required[93][94]. Einstein's General Relativity would suffer the same fate as Newton´s gravity before: i.e., rendered a most appropriate and useful approximation in certain somewhat limited domains.

Probably it is all too early to dismiss Einstein or tinker too much with his equations. Taking the nonlinear field self-interaction effects of General Relativity seriously can possibly explain both dark matter and dark energy[95][96]. Exploring the expansion of the universe using fundamental thermodynamical concepts for adiabatic conditions, some cooling has to be expected in a fluid approach[97]. This can be described with a Grüneisen-parameter, which is found as naturally embodied in the energy-momentum stress tensor in the Einstein field equations. A concept of "thermal time," with dynamical laws fully and only determined by correlations, has been considered as a possible basis for fully general-relativistic thermodynamics. In the presence of gravity, temperature is not constant in equilibrium in space. This Tolman-Ehrenfest effect linking thermodynamics and gravity can be derived by applying the equivalence principle to a key feature, i.e., the "speed of time," which is the ratio between the flow of thermal time and the flow of proper time[49][98]. This speed of time, in turn, can be identified as the local temperature. Carlo Rovelli takes thermal time as the centerpiece in an attempt to deconstruct and afterwards reconstruct time as the local order of events in a fundamentally relativistic account, with time resulting from a blurred vision of macroscopic states, i.e., course graining[99].

8. No need for dark matter nor dark energy

As decades of dedicated search for dark matter (particles) and dark energy have so far turned back basically empty-handed, gravity as an emergent phenomenon might be worthwhile to consider. Some version of MOND could almost certainly deliver an observed performance just as dark matter (or better); suitable approximations of General Relativity might do the same[95]. Heuristically, it has been sketched how space, gravity, and spacetime could emerge in a holographic scenario and rather directly yield Newton's law of gravitation[82][100]. Displacements change the entropy and lead to reaction forces. Gravity as an entropic force would then result from such changes in the information about the positions of material bodies. Generalization to relativity could further lead to the Einstein equations. The law of inertia might thus have an entropic origin following the equivalence principle. Entropic gravity can, in a toy model, also be linked to the quantum entanglement of small bits of spacetime information[101].

While it seems that there are several connections between quantum entanglement, gravity, and dark matter, there might also be mechanisms for dark energy[102][103]. For the latter, it might be even more natural to consider that our galaxy is located in a (not really very pronounced) under-dense region in the local universe. In this context, it is interesting to observe that MOND does predict more clumpy structures early on than plain (approximated) General Relativity / standard Lambda-cold dark matter (ΛCDM) models[92]. At the same time, James Webb Space Telescope (JWST) observations of the early universe are in strong tension with ΛCDM cosmology, which seems to favor hybrid models[104][105][106]. JWST observations yielded tensions with current models of galaxy evolution, detecting massive and apparently mature structures much earlier than expected[107]. One particular way some issues with the Hubble tension and galaxy formation could be fixed is with an early contribution of dark energy[108].

In any case, adapting/enhancing low-field gravity could look more promising than searching forever for seemingly directly non-observable dark matter or dark energy, the latter driving an observed accelerated expansion of the universe. Accepting General Relativity as a basis, one should take its non-linear self-interaction fully into account. This seems to offer explanations for the effects ascribed to the presence of dark matter as well as dark energy[95][96]. While effective gravity would be boosted over shorter distances inside denser regions, its influence over wide distances in between massive blocks would be diminished. A clumpy universe can give rise to "timescapes," i.e., clocks ticking with different speeds depending on whether they are situated in widely empty space or inside massive dense regions[92][109].

There might still be a little space for some dark baryonic matter in the vast expanses between far distant galaxies.

A not completely cancelled geometrical asymmetry during the late phases of the Big Bang might explain the observed very small lopsidedness of the CMB[60] and an uneven distribution of very big structures observed today[92].

Based on the latest JWST observations, dark energy has been hypothesized as waning ("thawing") compared to a few billion years ago[110]. This could qualitatively fit with the non-linear self-effects of General Relativity, which would certainly not establish a single static value for vacuum energy once and forever[94][95]. Dark energy, according to the fluid model, also turns out to be time-dependent in the current (dark energy-dominated) era[97].

9. No need or place for many worlds

It looks like all of the above can nicely fit with one real world, the universe, which we inhabit and observe. Quantum systems need classical framing, while purported effects from un-reflected uses of unitary quantum physics seem dispensable and not contributing too much to our understanding. Nice and elegant as a theory, which needs nothing else but itself for its own interpretation, might be, it has been argued before that not only quantum but even classical systems always require some separate reference[111].

It seems clear that for physical models, we have to stay inside the universe as observed (if we do not want to appeal to some metaphysical external god's eye perspective or help; doing this, in effect, by enthroning abstracted formalisms, including the postulation of perfectly plain stability for some relations, does not look like a convincing option).

Frames and records, as suggested here, can naturally match with time as described in Special and General Relativity. It has been demonstrated that Einstein´s equivalence principle can be generalized such that it applies for reference frames, which are associated with quantum systems, even when in a superposition of spacetimes[112]. This way, there seems to be no basic conflict between Quantum Theory and General Relativity. Nevertheless, that does not mean that massive bodies actually could be in superpositions; this appears to be prevented by inevitable phonons, which would be generated when trying to prepare a superposition of a massive body[113].

Spacetime cannot be infinitively smooth. At some (very small) scale, fluctuations must appear due to the quantum nature of many observables, and also time[39].

Attempts to arrive at classical manifest observations and one solid world based on fleeting quantum mechanical behavior have basically followed two routes: decoherence (staying inside the unitary QM formalism, but only for the entire system including the environment, and not for the respective quantum system alone) and modifying Schrödinger´s equation (postulating external influences). Here, it is proposed to leave QM inside alone, but effectively delimit completely isolated quantum systems by relatively hard boundaries at their preparation (or birth) and also at collapse (possibly rather smooth at this end if partly isolated).

One mandatory ingredient required for reconciling the quantum with the classical realm obviously is a certain level of randomness; some type of fluctuations, as described by thermodynamics, thus play an important role in all accounts. Conceptualizing decoherence as the transmitting / loss of information to an environment, end-boundaries are diluted as information leaks out of an incompletely isolated quantum system. With a tight relation between information and energy, in the end, the same amount of entropy as given by Landauer's principle is produced as a minimum for a quantum system to behave classically[114]. Like heat from mechanical friction, information related to entanglement does not return to resurrect some exact starting conditions; this is the arrow of time.

The standard von Neumann entropy is not suitable for characterizing extractable work from internally correlated systems; any lack of knowledge limits the amount of work that an observer can gain[115]. Strict energy conservation and the Jarzynski fluctuation theorem cannot be observed at the same time when extracting work from a quantum system in a thermal state[116].

In a very recent proposal of marrying quantum mechanics and gravity, fluctuations feature prominently, and it is hypothesized that small masses can be measured as fluctuating[117][118]. Zero-point fluctuations with particle-antiparticle pairs leading to a polarizability of the vacuum also play a decisive role in an attempt to address the cosmological enigma and derive (some) dark energy as vacuum energy from Casimir self-interaction of quantum electrodynamic fields[119]. Local contributions from Casimir self-interaction would most probably not preclude effects due to field self-interaction in General Relativity over wide distances[95][96], and the other way round.

10. Other parallels to the outside of the physical box

Any complete understanding of the universe has to cope with unknown unknowns and surely with principled limitations. These refer to the sheer understandability of physics on the one hand and to the limited capabilities of humans on the other. The “unreasonable effectiveness of mathematics in the natural sciences” as described by Eugene Wigner[120] does not come with a guarantee for infinite extension. On the contrary, mathematical impossibilities surely also constrain physical models. Additionally, any structure and theory must somehow match with human capacities for perception and cognition. Paraphrasing Immanuel Kant: “the conditions of the possibilities to experience objects are at the same time the conditions for the possible objects of this experience”[121]. Technical instruments built on the basis of thorough physical understanding have dramatically expanded human perception, often leading to serendipitous discoveries. In some (not so far) future, similar might happen to constrained human cognition. The Ouroboros Model offers an explanation of how our subjective experience of unfolding time structured in moments arises in iterations[1][121].

Looking at biology, we have learned that nature is a tinkerer, and assuming one divine streamlined master plan behind all physical reality might simply be misguided; and if nature were that clear in some end, that structure would only be accessible to us via cognition, which in turn is principally limited and relies to a large part on manyfold abstractions, which are linked and interwoven, but rather specific for clearly demarcated contexts[1].

The “natural“ but not naïve interpretation of quantum mechanics described above has to be considered local; everything we really know of happens in a (classical) context. Any prima facie non-local effect can solely be detected by employing *meta*-selections, the specifications of which cannot be transmitted without relying on at least some classical communication. Quantum mechanics is thus left in a situation akin to the case of mathematics: the impossibility to demonstrate some basic tenets of quantum reality without resorting to classical means can be seen as corresponding to Gödel´s incompleteness result. Some “external” reference for non-contradictory self-consistent grounding is required for “completeness”. This fundamental open-ended nature of relevant endeavors (in mathematics and for physics) does not prevent beautiful and useful results; on the contrary.

David Hilbert’s program of strict and complete axiomatization of mathematics (and physics) has been proven impossible. Kurt Gödel’s incompleteness proof, just the same as Alan Turing’s work with self-referring statements at their core, demonstrates this. The demonstrated irresolvable contradictions can be ascribed to a clash between a sought-for “eternal” (timeless) mathematical solid structure and a “dynamical” twist to it, which contraposes different “moments” (i.e., contexts). If that famous guy from Crete had made reference to the respective actual time in the real world and exclaimed “I lie now: (in this following interval, with this specific well-defined statement),” nobody would have ever bothered much.

In light of the above, taking time fully into account looks like offering the best way out, and this often offers a resolution of apparently infinite regress. Bhartṛhari and Julian Roberts had that idea (long) before[122].

Anyway, there are (individual) limits to human cognition and understanding. Natural laws carved out as straight(ened) important links in the web of dependencies have to be “accessible and simple,” and this constraint can only be expanded so much with artificial intelligence. Relations are selected as fundamental if they are clear and direct, useful, compatible with (almost) everything known, “elegant,”...; i.e., if they are in a way “beautiful,” similarly to daily life or art. It can be admitted that such a program might not be simply “realistic,” as there will always be something which we do not and cannot know, but the ambition and the obtained results overall certainly are not “anti-realistic.”

The topic of complexity, with a main distinction between problem classes belonging to P (solvable in polynomial time) versus NP (not solvable in polynomial time), might have some additional bearing on solidly establishing (and limiting) a basis for our (and machine) understanding of the world, which is principally achievable. A very rough analogy between graphs and quantum systems can be seen by identifying nodes with (classical records of) events and links with (timeless quantum mechanical) developments between these specific points. There are very many possible arrangements successively connecting nodes/events with one link exactly, while there is a limited number of possibilities for traversing links when nodes (events) are only encountered once on each route.

Comparing the number of possible Eulerian paths between a few nodes with the number of Hamiltonian paths, a tremendous imbalance is obvious (e.g., demonstrated in the nice animation in[123]); there are overwhelmingly more Hamiltonian paths. While it takes a slow exponential algorithm to find a solution for a Hamiltonian path, any route can be checked for correctness in polynomial time. For Euler graphs, both finding and verifying correct routes is easy with a fast polynomial algorithm. In Quantum Mechanics, events (with irreversible real records in entropy) are fewer than possible connections between them (links are manyfold and timeless).

It is tempting to speculate whether some type of Feynman integral approach, taking all possibilities into account, could be adapted and whether an associated Schrödinger-type equation for NP-hard problems could be found. Quantum computers might then have an edge, while classic simulations implemented with neuronal networks would be quite efficient up to some capacity limits. Roughly having all hubs and links in the mind at the same time and then starting with the strongest, i.e., internally most densely connected, clusters (coarse graining) in an iterative procedure is hypothesized to be a procedure by which humans address such problems; e.g., the one called the travelling salesman. Intermittently fixed anchoring points pave the way to a solution and fend off capacity limitations to some extent (at the expense of time required for a solution)[124].

Foregoing absolute optima helps to find near-optimum solutions efficiently. Bayesian processes, as recently often proposed as a blueprint for cognition, are NP-hard[125]. Limiting the material to be considered in a given context is one way to make it tractable[121]. In the end, the reachable universe is finite; this establishes some overall hard boundary conditions.

11. Conclusions

In a down-to-earth perspective, one specific result and immediate practical consequence of the above should be mentioned. Taking seriously that the transition of a system between quantum and real has a threshold given by Landauer’s principle, one should trivially focus on set-ups with very high relevant temperatures when trying to harness quantum “weirdness,” e.g., for quantum computers.

On the meta-level, which is the focus of this article, emancipating ourselves and renouncing the reliance on some external clockmaker or unique eternal formalism (and their respective perspectives), we have to assemble our understanding of the universe from what is rationally accessible to us inside. This follows from an obvious criterion of intellectual honesty. While that attitude does not exclude the contingent existence of other spheres[54], these cannot have a decisive place in any truly scientific account. The widest possible consistency between all known different constituents and their strongest achievable and testable interlinking is all we can aim to reach at a certain point in time. Approximating the emergence of reality by quantum decoherence seems to deliver similarly with basically the same accumulation of entropy in the environment in the end. For a fixed spectrum, no maximally entangled states can persist in the presence of noise[126]. Above a critical temperature, entanglement drops to zero, earlier described as the “sudden death of entanglement”[127]. The here emphasized “collapse” would be just a special “abrupt” case of the general process. There are limits to the application of the formalism; it can even be argued that in a somewhat paradoxical twist, objects could hypothetically decohere to profoundly non-quantum superpositions of massive bodies[113][128].

So, some type of “Ouroboros”-arrangements appears to be the best that we can ever achieve. For the here advocated three-legged approach, the Triskelion might be a fitting symbol; see Figure 1. If one insists, in a very abstract sense, this symbol could be taken as an encompassing god-eye’s view of the physical universe.

Figure 1. Triskelion symbol as an abstract shorthand for how Quantum Physics, Thermodynamics, and Relativity are interlinked and mutually induce each other[129].

For the whole ideograph, all three legs are necessary; no one is more basic or important than the others. No vicious circle nor indiscriminate associationism is meant, but an overarching consistent narrative with well-defined building blocks consistently embedded in some meaningful (time-) structure. Circles and loops are perfect, but more is required than just making ends meet; spirals (and helices) are preferred, and they have to have large enough diameters (and heights), embracing the knitwork of the entire universe, at least potentially as far as can be seen at any given time. In this somewhat fleeting picture strongly emphasizing emergences, one might try to find some basis starting with a concept of energy.

The situation actually is the same for physical theories, especially about the beginning of the universe, as it is for understanding consciousness and Free Will[121]. Also there, self-reference causes no problems as long as time is taken into account properly. Staying inside the known and rationally/scientifically accessible universe, the widest-ranging and well-organized self-referral is the best one can hope for. This entails pushing boundaries.

The proposal here is to see space as the primary basis for a better overview and put grainy emerging time as the "main culprit" for unavoidable fluctuations, which are essential for linking the quantum and real domains, at the forefront. Time itself is anchored in the expanding space of the universe, all void without material content[41]. Fluctuations themselves are “timeless” and not really “real” as long as they do not produce entropy and records, just as in isolated quantum systems.

The important point then is that releasing gravity from standing as a solitary pillar to some emergent status and tying it closer to thermodynamics could somewhat close a braided picture just the same as for the case of time. A self-consistent and intricate interplay of mutually self-reinforcing dependencies, like between quantum and classical mechanics, appears to be the best we can strive for. This is quite similar to the relation between spacetime and gravity, where neither space nor time would exist without energy or massive objects, the latter also experiencing gravity in the spacetime warped by masses, which in turn sense accelerations in time.

Identifying quantum physics as the basis for classical phenomena while quantum effects become real only when suitably framed by classical events then only seems appropriate. Similarly, understanding space and time as emergent from an underlying microscopic substrate dovetails with real irreversible time being established only in interactions and always involving some type of records and classical entropy generation. It is no deficiency that the highlighted derivations of General Relativity leverage ideas that had been developed from observations and models of gravity before[81][82]; one has to iteratively use the material that is available (at the time in question). The point is that the overall picture is grounded, coherent, and consistent with all available, in particular experimental, evidence.

What applies to dark matter, i.e., giving up a fruitless search for whatever exotic particle and rather accepting a view of emergence in the real universe, might be applicable the same for dark energy. While an increasing production of vacuum energy appears promising by attributing some repulsion to the emerging number of possibilities with growing space[119], living in a relatively empty local bubble might also be worthwhile a consideration[92][109]. The proposal of non-linear self-interaction in General Relativity appears to offer a promising avenue for research, as it could even account for changes (reductions) in dark energy over longer time scales, as recently reported[95][96][110]. This conspires with new findings when modeling the universe as an adiabatic fluid[97].

Running against the fundamental human wish for simple explanations, there is no reason why nature should not have settled with a constellation combining many diverse effects and contributions, on the contrary.

A compound conceptualization with growth plates (“Wachstumsfugen”, the German word is better by highlighting the malleable space between more solid parts) instead of smooth and seamless uniformity might be the best way to describe our many-faceted universe. The overall picture is more like a mosaic than a smooth and continuous canvas. In restricted specific contexts (in praxis, with different approximations and associated ranges of applicability) if --> then causal dependencies can be sought for and often successfully delineated. Different perspectives corresponding to different models and approximations can be most useful and effective in some contexts but detrimental for addressing other problems[95][96]. In an effective web of concepts and relations, more than one path between any two points can be expected. Actually, the denser the web and the finer the mesh, the more complete the picture, the deeper and encompassing the understanding, which then effectively unites many diverse perspectives[121]. This does not fundamentally exclude an underlying "plan of a watchmaker"; actually, nothing inside the universe could do this, just the same as for confirming one.

The author hopes that with this very rough sketch, a thicket of intricate formalisms could be recast in an emancipated, enlightened, and "democratic" perspective, and the whole somewhat ordered in a self-consistent, coarsely systematic, at least not completely haphazard way (although some measure of uncertainty or chaos appears indispensable in order to do justice to a full model of the universe). The "three pillars" in the end are abstractions themselves in a web of manyfold dependencies and (abstractable) regularities. Bending trajectories to straight, as suggested with the Alena Tensor, offers unexpected new perspectives and links[130]. "Time" in this picture appears as a most versatile throughgoing abstraction related to the order of events.

There is nothing like "substance", which would obey the definition of Baruch de Spinoza, i.e., something that is "in itself and is conceived through itself, that is, that whose concept does not require the concept of another thing, from which it must be formed"[131]. Recent investigations in quantum reference frames lead to similar conclusions regarding localization and time, leaving no ground for "absoluteness"[6]. The concept of substance, like that of physical laws, are abstractions, i.e., Platonic figures, grounded in, but detached from many details of a braided underlying fabric of reality. Reality is everything together, emerging from the interplay of many diverse strands and relations. Unquestionably reachable from the inside, there is nothing like one fundamental particle, or one Theory of Everything, or one formalism, or one basic eternal truth, and neither any one God. There is nothing like an Archimedean point.

Facts are not relative/private other than described by Relativity and inherent limitations for communication, even if there can be many diverse perspectives. A detailed formalism allows for the full reconciliation of relativistic and quantum notions of causality. Experiments performed in classical spacetime can be explained in terms of a definite and acyclic causal order at a fine-grained level[51][52][53].

Ultimately, overall consistency with all accessible boundary conditions at a time and including developments is the touchstone for “truth”, i.e., fully convincing models, which allow us to explain known facts and to formulate interesting predictions.

An ontology like the one by Nicolai Hartman is demanded, at the latest, as soon as (self-) interactions and combinations begin to build up higher-order phenomena[54]. While a certain reaction between two entities interacting might be the only possible one in a certain context, a lot of development and time might have been necessary to arrive at that particular state. The gestation of an embryo and a full bird inside an egg need very little input in terms of external energy/heat, but the process starts from a most peculiar point with a tremendous history to draw effective information from. Synergetics, as developed by Hermann Haken and emphasizing time, offers the best chances to describe how different levels of organization can interact and make novel features and structures emerge[132]. Hermann Haken and Philipp Warren Anderson realized, amongst others, the importance of the sheer quantity of any constituent[133]. The very concept of emergence can be traced at least to Nicolai Hartmann, and probably much longer back[54]. Long ignored, it recently received some interest with the advent of new mathematical formalisms with causation going bottom-up as well as top-down[134][135][136][137].

Following this line of thinking, it is attempted here to sketch that a self-organizing approach with mutual dependencies, constraints, and promotions, leading to the unfolding emergence of our one reality, can form a suitable basis for the existence of the universe and our understanding of it. Starting from any one chosen “cornerstone”, the others can be found, explained, and understood iteratively; in the triskelion symbol: tracing one uninterrupted line through its full length and through all turns.

The overall encompassing picture is claimed to be one of (“mutually induced”) emergence. As “more is different” holds already in the context of the quantity of one part alone, it should come as no surprise that this principle is valid when many diverse contributions are effective together[133]. The main focus of attention related to emergence usually is on attempts to explain some higher level of organization on the basis of the involved constituents. In valid examples, the other side of the coin is obvious but often neglected; any overarching emerged structure will somewhat inevitably be undermined as soon as one delves into specific deep details. The grand big picture can easily get out of sight, and it might, in fact, even be destroyed by too limited myopia.

Transformations involving energy or information in the real world are inevitably associated with losses for a source and with entropy production. Some principal uncertainty alone, and especially adhering to some type of energy/time (entropy/time) uncertainty relations, forbids 100% efficiency and perfectly sharp demarcations. Even beyond that, Quantum Mechanics is not necessary for the unpredictability of the future of any sufficiently complex system. Entropy is not the same as information or a simple lack thereof. Entropy is relative, and information is information only for a prepared (suitably knowledgeable) recipient; coarse graining prevails, and it is most often the case that only fractions of the total content can be transmitted and decoded. A most stupid guy, probably not even able to read a single word, knows that burning a (holy) book hurts the targeted audience. Collecting all photons emitted in the process could not bring back the meaningful content.

Even if still striving for some type of unification, a non-hierarchical layout of physical theory has to some extent been proposed before by Carl Friedrich von Weizsäcker in the format of a "Kreisgang" (walking in a circle) through a web of relations and dependencies[138]. By establishing records at disruptions, the unitary evolution of quantum states, which is information-preserving and time-reversible, can be reconciled with the global evolution of the universe following the second law of thermodynamics, which, in general, is neither. Poincaré recurrence is a mathematical construct not applying to the real non-conservative world; even inside the quantum realm, ergodicity can be broken because of destructive interferences[139].

Emphasizing a braided layout in a dynamic "process-view," self-referring and with high interconnectedness, could be seen as an attempt to combine Eastern and Western traditions, which, amongst others, have repeatedly been found to put different weights on context as part of the respective cultures[140].

To what extent the widespread search for one theory of everything (like earlier: the philosopher's stone) can be traced to a preference for monocausal thinking (probably grounded in monotheism or following from the same roots) would be another interesting topic; – for history, cognitive science, and sociology. "Beauty" and "elegance" ascribed to (mathematical and physical) theories (as well as to pieces of art) are hypothesized to follow from the same roots in human cognitive processes[1][121].

Letting go of any form of unique metaphysical goal-directedness, the here suggested layout and path forward is probably but one of several or many possibilities to approach an overall consistent picture (each emphasizing different constituents and relations). This should be seen as encouraging and as a genuine witness of possibly achieving some comprehensive understanding covering many facets and including various diverse chains of arguments.

(Physical) theories (conceptualizations, models) are not all equal; they can self-reflectively and - consistently be ranked according to criteria including how big their “diameter” is, i.e., whether or not they cover a large range extending over many layers in an ontological hierarchy, how widely applicable and accurate their results are, how solid they appear, how deeply grounded and based on well-established facts without leaving large gaps, how important their field of application actually is, whether they are open to progress or better even promote improvement and growth, and many more; – with some of the demanded attributes and their weights most likely changing (mostly slightly) with the accumulation of sound knowledge over time. Identified grounding layers with many (causal) links emanating are in a privileged position. Uncertainty relations / trade-offs appear to be essential as one can never be sure to have taken all potentially relevant parameters in interesting contexts into account properly, – except in very restricted cases.

For a very first shot aiming at a really big scientifically fully grounded and coherent picture without appealing to supranatural powers, the author took the liberty to suppress many details, leaving a lot of room for serendipity. Attempting a coarse but encompassing view of how it all could fit together hopefully helps to turn attention and effort to promising directions[121].

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References

1. [a, b, c, d, e]*Thomsen K. "The Ouroboros Model in the light of venerable criteria". Neurocomputing. 74 (1-3): 121-128. doi:10.1016/j.neucom.2009.10.031.*
2. ^*Bohr N. Can Quantum-Mechanical Description of Physical Reality be Considered Complete? Reprinted in J. Faye and H. J. Folse (1998) (eds.), The Philosophical Writings of Niels Bohr, Vol. IV: Causality and Complementarity. Woodbridge: Ox Bow press UK.*
3. ^*Lamb WE Jr. "An operational interpretation of nonrelativistic quantum mechanics". Physics Today. 22 (4): 23-28. doi:10.1063/1.3035523.*
4. [a, b]*Di Biagio A, Donà P, Rovelli C. "The arrow of time in operational formulations of quantum theory". Quantum. 5: 520. doi:10.22331/q-2021-08-09-520.*

5. ^Aubrun G, Lami L, Palazuelos C, Plávala M. "Entanglement and Superposition Are Equivalent Concepts in Any Physical Theory". Physical Review Letters. 128 (16): 160402. doi:10.1103/PhysRevLett.128.160402.
6. a, bV. Kabel et al., Identification is Pointless: Quantum Reference Frames, Localisation of Events, and the Quantum Hole Argument, https://doi.org/10.48550/arXiv.2402.10267
7. ^V. Baumann and Č. Brukner, Wigner's friend's memory and the no-signaling principle, https://quantum-journal.org/papers/q-2024-09-25-1481/pdf/
8. a, b, cRovelli C. "Memory and Entropy". Entropy. 24 (8): 1024. doi:10.3390/e24081022.
9. ^Landauer R. "Irreversibility and Heat Generation in the Computing Process". IBM Journal of Research and Development. 5 (3): 183–191. doi:10.1147/rd.53.0183.
10. ^Bennett CH. "Notes on Landauer's principle, reversible computation, and Maxwell's Demon". Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics. 34 (3): 501–510. doi:10.1016/S1355-2198(03)00039-X.
11. a, b, cW.C. Myrvold, Shakin' All Over: Proving Landauer's Principle without neglect of fluctuations (2020) eprint: arXiv:2007.11748, https://doi.org/10.48550/arXiv.2007.11748
12. a, b, cThomsen K. "Timelessness Strictly inside the Quantum Realm". Entropy. 23 (6): 772. doi:10.3390/e23060772.
13. ^Feynman RP, Hibbs AR. Quantum Mechanics and Path Integrals. New York, McGraw-Hill, 1965.
14. ^P. Faist, Welcome to the entropy zoo, https://phfaist.com/entropyzoo
15. ^D. Šafránek, et al., A brief introduction to observational entropy, https://arxiv.org/pdf/2008.04409
16. ^P. Strasberg and J. Schindler, Comparative Microscopic Study of Entropies and their Production, https://scipost.org/SciPostPhys.17.5.143
17. a, bL. Herrera, Modified Landauer Principle According to Tsallis Entropy, Entropy 26, 931, 2024, https://www.mdpi.com/1099-4300/26/11/931
18. ^Chua EYS, Callender C. No Time for Time from No-Time, https://doi.org/10.48550/arXiv.2303.14854
19. a, bGarcia-Pintos LP, Nicholson SB, Green JR, del Campo A, Gorshkov AV. "Unifying Quantum and Classical Speed Limits on Observables". Physical Review X. 12 (1): 011038. doi:10.1103/PhysRevX.12.011038.
20. ^Mertens L, Wesseling M, Vercauteren N, Corrales-Salazar A, van Wezel J. "Inconsistency of linear dynamics and Born's rule". Physical Review A. 104 (5): 052224. doi:10.1103/PhysRevA.104.052224.
21. ^V. Shevchenko, Quantum measurements and Landauer's principle, EPJ Web of Conferences 95, 03034, 2015, https://www.epj-conferences.org/articles/epjconf/abs/2015/14/epjconf_icnfp2014_03034/epjconf_icnfp2014_03

034.html

22. ^Yoon TH, Cho M. "Quantitative complementarity of wave-particle duality". Science Advances. 7 (34): eabi9268. doi:10.1126/sciadv.abi9268.
23. ^Hong S, Kim YS, Cho YW, Kim J, Lee SW, Lim HT. "Demonstration of Complete Information Trade-Off in Quantum Measurement". Physical Review Letters. 128 (5): 050401. doi:10.1103/PhysRevLett.128.050401.
24. ^Kewming MJ, Shrapnel S. "Entropy production and fluctuation theorems in a continuously monitored optical cavity at zero temperature". Quantum. 6: 685. doi:10.22331/q-2022-04-13-685.
25. ^Coles P, Kaniewski J, Wehner S. "Equivalence of wave-particle duality to entropic uncertainty". Nature Communications. 5 (1): 5814. doi:10.1038/ncomms6814.
26. ^D. Spegel-Lexne, et al., Experimental demonstration of the equivalence of entropic uncertainty with wave-particle duality, Science Advances 10, 2024, https://www.science.org/doi/10.1126/sciadv.adr2007
27. ^Spekkens RW. "Contextuality for preparations, transformations, and unsharp measurements". Physical Review A. 71 (5): 052108. doi:10.1103/PhysRevA.71.052108.
28. ^Matsushika T, Hofmann HF. "Dependence of measurement outcomes on the dynamics of quantum coherent interactions between the system and the meter". Physical Review Research. 5 (3): 033064. doi:10.1103/PhysRevResearch.5.033064.
29. ^Frauchiger D, Renner R. "Quantum theory cannot consistently describe the use of itself". Nature Communications. 9 (1): 1–10. doi:10.1038/s41467-018-05739-8.
30. ^Hance JR, Ji M, Hofmann HF. "Contextuality, coherences, and quantum Cheshire cats". New Journal of Physics. 25 (11): 113028. doi:10.1088/1367-2630/ad0bd4.
31. ^Kupczynski M. Contextuality or nonlocality: what would John Bell choose today? Entropy. 2023;25(2):280. doi:10.3390/e25020280.
32. ^Khrennikov A. Is the devil in h? Entropy. 2021;23(5):632. doi:10.3390/e23050632.
33. ^Khrennikov A. Contextuality, complementarity, signaling, and Bell tests. Entropy. 2022;24(10):1380. doi:10.3390/e24101380.
34. ^Rauch D, Handsteiner J, Hochrainer A, Gallicchio J, Friedman AS, Leung C, et al. Cosmic Bell Test Using Random Measurement Settings from High-Redshift Quasars. Physical Review Letters. 2018;121(8):080403. doi:10.1103/PhysRevLett.121.080403.
35. ^Schlatter A. On the reality of quantum collapse and the emergence of space-time. Entropy. 2019;21(3):323. doi:10.3390/e21030323.

36. a, bLucia U, Grisolia G. *Thermodynamic Definition of Time: Considerations on the EPR Paradox. Mathematics. 2022;10(15):2711. doi:10.3390/math10152711.*

37. ^Tanaka S. *Appearance of thermal time. Foundations of Physics. 2021;51(2):34. doi:10.1007/s10701-021-00445-w.*

38. ^Erker P, Mitchison MT, Silva R, Woods MP, Brunner N, Huber M. *Autonomous quantum clocks: does thermodynamics limit our ability to measure time? Physical Review X. 2017;7(3):031022. doi:10.1103/PhysRevX.7.031022.*

39. a, bPearson AN, Guryanova Y, Erker P, Laird EA, Briggs GAD, Huber M, et al. *Measuring the thermodynamic cost of timekeeping. Physical Review X. 2021;11(2):021029. doi:10.1103/PhysRevX.11.021029.*

40. a, b, cGuryanova Y, Friis N, Huber M. *Ideal projective measurements have infinite resource costs. Quantum. 2020;4:222. doi:10.22331/q-2020-01-13-222.*

41. a, b, cGold T. *The arrow of time. Am. J. Phys.. 1982;30:403-410. doi:10.1007/s10699-006-0007-y.*

42. ^Page DN, Wootters WK. *Evolution without evolution: Dynamics described by stationary observables. Physical Review D. 1983;27(12):2885-2892. doi:10.1103/PhysRevD.27.2885.*

43. ^Paiva IL, Lobo AC, Cohen E. *Flow of time during energy measurements and the resulting time-energy uncertainty relation. Quantum. 2022;6:683. doi:10.22331/q-2022-04-07-683.*

44. ^Shettell N, Centrone F, Garcia-Pintos LP. *Bounding the minimum time of a quantum measurement. Quantum. 2023;7:1182. doi:10.22331/q-2023-11-14-1182.*

45. ^Kuramochi Y, Tajima H. *Wigner-Araki-Yanase theorem for continuous and unbounded conserved observables. Physical Review Letters. 2023;131(21):210201. doi:10.1103/PhysRevLett.131.210201.*

46. ^Jacobs K. *Quantum measurement and the first law of thermodynamics: The energy cost of measurement is the work value of the acquired information. Physical Review E. 2012;86(4):040106. doi:10.1103/PhysRevE.86.040106.*

47. ^Zeilinger A. *A foundational principle for quantum mechanics. Foundations of Physics. 1999;29(4):631-643. doi:10.1023/A:1018820410908.*

48. a, bRubino G, Manzano G, Brukner Č. *Quantum superposition of thermodynamic evolutions with opposing time's arrows. Communications Physics. 2021;4:251. doi:10.1038/s42005-021-00759-1.*

49. a, bMilburn GJ. *The thermodynamics of clocks. Contemporary Physics. 2020;61(2):69-95. doi:10.1080/00107514.2020.1837471.*

50. ^Rovelli C. *How causation is rooted into thermodynamics. Philosophy of Physics. 2023;1(1):11. doi:10.31389/pop.46.*

51. [a, b]*Vilasini V, Renner R. Fundamental Limits for Realizing Quantum Processes in Spacetime. Physical Review Letters. 2024;133(8):080201. doi:10.1103/PhysRevLett.133.080201.*
52. [a, b]*Vilasini V, Renner R. Embedding cyclic information-theoretic structures in acyclic space-time: No-go results for indefinite causality. Physical Review A. 2024;110(2):022227. doi:10.1103/PhysRevA.110.022227.*
53. [a, b]*M. Salzger, Connecting indefinite causal order processes to composable quantum protocols in a spacetime, https://arxiv.org/abs/2304.06735*
54. [a, b, c, d]*Hartmann N. Die Erkenntnis im Lichte der Ontologie, mit einer Einführung von Josef Stallmach; Felix Meiner Verlag: Hamburg, Germany, 1982.*
55. ^*Riek R, Chatterjee A. Causality in discrete time derived from Maupertuis reduced action principle. Entropy. 2021;23(9):1212. doi:10.3390/e23091212.*
56. ^*Feng G, Huang J. A heuristic resolution of the Abraham–Minkowski controversy. The European Physical Journal Plus. 2021;136(5):520. doi:10.1140/epjp/s13360-021-01523-8.*
57. ^*Koivurova M, Robson CW, Ornigotti M. Time-varying media, relativity, and the arrow of time. Optica. 2023;10(10):1398. doi:10.1364/OPTICA.494630.*
58. ^*J. Paczos et al., Covariant quantum field theory of tachyons, Phys. Rev. D 110, 015006, 2024, https://journals.aps.org/prd/abstract/10.1103/PhysRevD.110.015006*
59. ^*Aharonov Y, Bergmann PG, Lebowitz JL. Time Symmetry in the Quantum Process of Measurement. Physical Review. 1964;134:B1410–B1416.*
60. [a, b]*Planck Collaboration, Ade PAR, Aghanim N, Armitage-Caplan C, Arnaud M, Ashdown M, et al. Planck2013 results. XXIII. Isotropy and statistics of the CMB. Astronomy & Astrophysics. 2014;571:A23. doi:10.1051/0004-6361/201321534.*
61. ^*Schulman LS. "Source of the observed thermodynamic arrow". Journal of Physics: Conference Series. 174: 012022. doi:10.1088/1742-6596/174/1/012022.*
62. [a, b]*R. Penrose, Before the Big Bang: an outrageous new perspective and its implications for particle physics, Proceedings of EPAC 2006, Edinburgh, Scotland, 2006.*
63. ^*Rovelli C. "Where was past low-entropy?". Entropy. 21 (5): 466. doi:10.3390/e21050466.*
64. ^*Boyle L, Turok N. "Thermodynamic solution of the homogeneity, isotropy and flatness puzzles (and a clue to the cosmological constant)". Physics Letters B. 849: 138442. doi:10.1016/j.physletb.2024.138442.*
65. [a, b, c]*Bekenstein JD. "Universal upper bound on the entropy-to-energy ratio for bounded systems". Physical Review D. 23 (2): 287-298. doi:10.1103/PhysRevD.23.287.*

66. ^Basso MLW, Maziero J, Céleri LC. "The irreversibility of relativistic time-dilation". Classical and Quantum Gravity. 40 (19): 195001. doi:10.1088/1361-6382/acf089.
67. ^V. Papadopoulos, J. Wenger, and C. Hongler, Arrows of Time for Large Language Models, https://doi.org/10.48550/arXiv.2401.17505
68. ^A.G. Riess et al., A Comprehensive Measurement of the Local Value of the Hubble Constant with 1 km s-1 Mpc-1 Uncertainty from the Hubble Space Telescope and the SH0ES Team, The Astrophysical Journal Letters 934, 2022, https://iopscience.iop.org/article/10.3847/2041-8213/ac5c5b
69. ^W.L. Freedman et al., Status Report on the Chicago-Carnegie Hubble Program (CCHP): Three Independent Astrophysical Determinations of the Hubble Constant Using the James Webb Space Telescope, https://doi.org/10.48550/arXiv.2408.06153
70. ^Albrecht A, Steinhardt PJ. "Cosmology for Grand Unified Theories with Radiatively Induced Symmetry Breaking". Physical Review Letters. 48 (17): 1220-1223. doi:10.1103/PhysRevLett.48.1220.
71. ^Ijjas A, Loeb A, Steinhardt PJ. "Inflationary paradigm in trouble after Planck 2013". Physics Letters B. 723 (4-5): 261–266. doi:10.1016/j.physletb.2013.05.023.
72. ^Dittrich B, Höhn PA. "Canonical simplicial gravity". Classical and Quantum Gravity. 29 (11): 115009. doi:10.1088/0264-9381/29/11/115009.
73. ^J. Cotler and A. Strominger, The Universe as a quantum encoder, https://doi.org/10.48550/arXiv.2201.11659
74. ^Tolman RC. "On the Weight of Heat and Thermal Equilibrium in General Relativity". Physical Review. 35 (8): 904-924. doi:10.1103/PhysRev.35.904.
75. ^Santiago J, Visser M. "Tolman temperature gradients in a gravitational field". European Journal of Physics. 40 (2): 025604. doi:10.1088/1361-6404/aaff1c.
76. ^E.K. Anderson, et al. Observation of the effect of gravity on the motion of antimatter, Nature 621, 716, 2023, https://doi.org/10.1038/s41596-023-06527-1
77. ^Blas D. "Theoretical aspects of antimatter and gravity". Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. 376 (2116): 20170277. doi:10.1098/rsta.2017.0277.
78. ^Stefan Meyer Institute for subatomic Physics Austrian Academy of Sciences, https://antimatter.at/welcome/description/cpt/#:~:text=An%20even%20tiny%20violation%20of, atom%20consisting%20purely%20of%20antimatter
79. ^Paul Scherrer Institut, Switzerland, https://www.psi.ch/en/nedm (retrieved 23 October 2024)
80. ^Jacobson T. "Thermodynamics of Spacetime: The Einstein Equation of State". Physical Review Letters. 75 (7): 1260-1263. doi:10.1103/PhysRevLett.75.1260.

81. [a], [b] *Verlinde E. "On the origin of gravity and the laws of Newton". Journal of High Energy Physics. 2011 (4): 029. doi:10.1007/JHEP04(2011)029.*

82. [a], [b], [c] *K. Ourabah, The other way round: from alternative gravity to entropy, Class. Quantum Grav. 41, 015010, 2024, https://iopscience.iop.org/article/10.1088/1361-6382/ad0eeb*

83. ^ *Jacobson T. "Entanglement Equilibrium and the Einstein Equation". Physical Review Letters. 116: 201101.*

84. ^ *J.D. Bekenstein, Black Hole and Entropy, Phys. Rev. D 7, 2333–2346, 1973, https://journals.aps.org/prd/abstract/1guayo-Ortiz, 0.1103/PhysRevD.7.2333*

85. ^ *ChunJun Cao and S.M. Carroll, Bulk entanglement gravity without a boundary: Towards finding Einstein's equation in Hilbert space, https://journals.aps.org/prd/pdf/10.1103/PhysRevD.97.086003*

86. ^ *Begeman KG, Broeils AH, Sanders RH. "Extended rotation curves of spiral galaxies: dark haloes and modified dynamics". Monthly Notices of the Royal Astronomical Society. 249 (3): 523-537. doi:10.1093/mnras/249.3.523.*

87. ^ *Wang L, Chen DM. "Comparison of Modeling SPARC spiral galaxies' rotation curves: halo models vs. MOND". Research in Astronomy and Astrophysics. 21 (11): 271. doi:10.1088/1674-4527/21/11/271.*

88. ^ *Mistele T, McGaugh S, Lelli F, Schombert J, Li P. "Indefinitely Flat Circular Velocities and the Baryonic Tully–Fisher Relation from Weak Lensing". The Astrophysical Journal Letters. 969 (1): L3. doi:10.3847/2041-8213/ad54b0.*

89. ^ *Chae KH. "Robust Evidence for the Breakdown of Standard Gravity at Low Acceleration from Statistically Pure Binaries Free of Hidden Companions". The Astrophysical Journal. 960 (2): 114. doi:10.3847/1538-4357/ad0ed5.*

90. ^ *X. Hernandez, Kyu-Hyun Chae, and A. Aguayo-Ortiz, A critical review of recent Gaia wide binary gravity tests, MNRAS 533, 729–742, 2024, https://academic.oup.com/mnras/article/533/1/729/7721637*

91. ^ *Skordis C, Złośnik T. "New relativistic theory for modified newtonian dynamics". Physical Review Letters. 127 (16): 161302, 2021. doi:10.1103/PhysRevLett.127.161302.*

92. [a], [b], [c], [d], [e] *Mazurenko S, Banik I, Kroupa P, Haslbauer M. "A simultaneous solution to the Hubble tension and observed bulk flow within 250 h-1 Mpc". Monthly Notices of the Royal Astronomical Society. 527 (3): 4388-4396, 2023. doi:10.1093/mnras/stad3357.*

93. ^ *Bekenstein JD. "Relativistic gravitation theory for the modified Newtonian dynamics paradigm". Physical Review D. 70 (8): 083509, 2004. doi:10.1103/PhysRevD.70.083509.*

94. [a], [b] *Bekenstein JD. "Relativistic MOND as an alternative to the dark matter paradigm". Nuclear Physics A. 827 (1-4): 555c-560c, 2009. doi:10.1016/j.nuclphysa.2009.05.122.*

95. a, b, c, d, e, f, gDeur A. "An explanation for dark matter and dark energy consistent with the standard model of particle physics and General Relativity". The European Physical Journal C. 79 (10): 883, 2019. doi:10.1140/epjc/s10052-019-7393-0.
96. a, b, c, d, eDeur A. Comment on "Does gravitational confinement sustain flat galactic rotation curves without dark matter?" https://doi.org/10.48550/arXiv.2306.00992.
97. a, b, cSquillante L, Gomes GO, Mello IF, Nogueira G, Seridonio AC, Lagos-Monaco RE, Souza Md. "Exploring the expansion of the universe using the Grüneisen parameter". Results in Physics. 57: 107344, 2024. doi:10.1016/j.rinp.2024.107344.
98. ^Rovelli C, Smerlak M. "Thermal time and Tolman–Ehrenfest effect: 'temperature as the speed of time'". Classical and Quantum Gravity. 28 (7): 075007, 2011. doi:10.1088/0264-9381/28/7/075007.
99. ^Rovelli C. The order of time. Penguin Random House, 2018.
100. ^Stephens CR, 't Hooft G, Whiting BF. "Black hole evaporation without information loss". Classical and Quantum Gravity. 11 (3): 621–648, 1994. doi:10.1088/0264-9381/11/3/014.
101. ^Swingle B. "Spacetime from entanglement". Annual Review of Condensed Matter Physics. 9 (1): 345-359, 2018. doi:10.1146/annurev-conmatphys-033117-054219.
102. ^Watson CN. "Theory of gravity dependent on entropy". Reports in Advances of Physical Sciences. 7: 2350006, 2023. doi:10.1142/S2424942423500068.
103. ^Schlatter A, Kastner RE. "Gravity from transactions: fulfilling the entropic gravity program". Journal of Physics Communications. 7 (6): 065009, 2023. doi:10.1088/2399-6528/acd6d7.
104. ^McGaugh SS, Schombert JM, Lelli F, Franck J. "Accelerated Structure Formation: The Early Emergence of Massive Galaxies and Clusters of Galaxies". The Astrophysical Journal. 976. https://iopscience.iop.org/article/10.3847/1538-4357/ad834d.
105. ^Gupta R. "JWST early universe observations and ΛCDM cosmology". Monthly Notices of the Royal Astronomical Society. 524 (3): 3385-3395, 2023. doi:10.1093/mnras/stad2032.
106. ^Le Conte ZA, Gadotti DA, Ferreira L, Conselice CJ, de Sá-Freitas C, Kim T, Neumann J, Fragkoudi F, Athanassoula E, Adams NJ. "A JWST investigation into the bar fraction at redshifts $1 \leq z \leq 3$". Monthly Notices of the Royal Astronomical Society. 530 (2): 1984-2000, 2024. doi:10.1093/mnras/stae921.
107. ^Wang B, et al. "RUBIES: Evolved Stellar Populations with Extended Formation Histories $z \sim 7$–8 in Candidate Massive Galaxies Identified with JWST/NIRSpec". The Astrophysical Journal Letters. 969, 2024. https://iopscience.iop.org/article/10.3847/2041-8213/ad55f7.

108. ^*Shen X, Vogelsberger M, Boylan-Kolchin M, Tacchella S, Naidu RP. "Early galaxies and early dark energy: a unified solution to the hubble tension and puzzles of massive bright galaxies revealed by JWST". Monthly Notices of the Royal Astronomical Society. 533 (4): 3923-3936, 2024. doi:10.1093/mnras/stae1932.*

109. a, b*Seifert A, Lane ZG, Galoppo M, Ridden-Harper R, Wiltshire DL. "Supernovae evidence for foundational change to cosmological models". Monthly Notices of the Royal Astronomical Society: Letters. 537 (1): L55–L60, 2025. doi:10.1093/mnrasl/slae112.*

110. a, b*DESI collaboration. https://data.desi.lbl.gov/doc/papers/ (retrieved 23 October 2024).*

111. ^*Schumacher B, Westmoreland MD. "Interpretation of quantum theory: the quantum „grue-bleen“ problem". Entropy. 24 (9): 1268, 2022. doi:10.3390/e24091268.*

112. ^*Giacomini F, Brukner Č. "Quantum superposition of spacetimes obeys Einstein´s equivalence principle". AVS Quantum Science. 4, 2022. doi:10.1116/5.0070018.*

113. a, b*Henkel C, Folman R. "Universal limit on spatial quantum superpositions with massive objects due to phonons". https://doi.org/10.48550/arXiv.2305.15230.*

114. ^*Yan L, Ge X. "A Thermodynamic Study on Information Power in Communication Systems". Entropy. 26 (8): 650, 2024. https://www.mdpi.com/1099-4300/26/8/650.*

115. ^*Dahlsten OCO, Renner R, Rieper E, Vedral V. "Inadequacy of von Neumann entropy for characterizing extractable work". New Journal of Physics. 13: 053015, 2011. https://iopscience.iop.org/article/10.1088/1367-2630/13/5/053015.*

116. ^*Hovhannisyan KV, Imparato A. "Energy conservation and fluctuation theorem are incompatible for quantum work". https://quantum-journal.org/papers/q-2024-05-06-1336/.*

117. ^*Oppenheim J. "A postquantum theory of classical gravity?". Physical Review X. 13 (4): 041040, 2023. doi:10.1103/PhysRevX.13.041040.*

118. ^*Oppenheim J, Sparaciari C, Šoda B, Weller-Davies Z. "Gravitationally induced decoherence vs space-time diffusion: testing the quantum nature of gravity". Nature Communications. 14 (1): 7910, 2023. doi:10.1038/s41467-023-43348-2.*

119. a, b*Tkatchenko A, Fedorov DV. "Casimir self-interaction energy density of quantum electrodynamic fields". Physical Review Letters. 130 (4): 041601, 2023. doi:10.1103/PhysRevLett.130.041601.*

120. ^*Wigner EP. "The unreasonable effectiveness of mathematics in the natural sciences. Richard Courant lecture in mathematical sciences delivered at New York University, May 11, 1959". Communications on Pure and Applied Mathematics. 13 (1): 1–14, 1960. doi:10.1002/cpa.3160130102.*

121. a, b, c, d, e, f, g *Thomsen K (2024). "A challenge in A(G)I, cybernetics revived in the Ouroboros Model as one algorithm for all thinking". Artificial Intelligence and Autonomous Systems. doi:10.55092/aias20240001.*
122. ^ *Wikipedia article titled „Liar Paradox“, accessed 11 March 2024.*
123. ^ *Brubaker B. "Complexity theory’s 50-year journey to the limits of knowledge". Quantamagazine. 17 August, 2023. https://www.quantamagazine.org/complexity-theorys-50-year-journey-to-the-limits-of-knowledge-20230817/.*
124. ^ *Thomsen K (2008). "Is Quantum Mechanics Needed to Explain Consciousness?". NeuroQuantology. 6: 43-45. https://arxiv.org/pdf/0711.1976.*
125. ^ *Kwisthout J, van Rooij I (2020). "Computational Resource Demands of a Predictive Bayesian Brain". Computational Brain & Behavior. 3: 174–188. https://link.springer.com/article/10.1007/s42113-019-00032-3.*
126. ^ *de Vicente JI (2024). "Maximally Entangled Mixed States for a Fixed Spectrum Do Not Always Exist". Phys. Rev. Lett. 133: 050202. https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.133.050202.*
127. ^ *Bakshi A, Liu A, Moitra A, Tang E. "High-Temperature Gibbs States are Unentangled and Efficiently Preparable". doi:10.48550/arXiv.2403.16850.*
128. ^ *Filatov S, Auzinsh M (2022). "Unitarity of decoherence implies possibility of decoherence-like dynamics towards macroscopic superpositions". Entropy. 24 (11): 1546. doi:10.3390/e24111546.*
129. ^ *Wikipedia article titled „Triskelion“, image downloaded 25 February, 2024.*
130. ^ *Ogonowski P, Skindzier P (2024). "Alena Tensor in unification applications". Physica Scripta. 100. https://iopscience.iop.org/article/10.1088/1402-4896/ad98ca.*
131. ^ *Spinoza B (1925). Opera, Ethics, Part 3. Carl Winters, Heidelberg.*
132. ^ *Haken H (1983). Synergetics, An Introduction: Nonequilibrium Phase Transitions and Self-Organization in Physics, Chemistry, and Biology. 3rd ed.; Springer-Verlag: New York, NY, USA.*
133. a, b *Anderson PW (1972). "More is Different". Science. 177 (4047): 393–396. https://cse-robotics.engr.tamu.edu/dshell/cs689/papers/anderson72more_is_different.pdf.*
134. ^ *Comolatti R, Hoel E (2022). "Causal emergence is widespread across measures of causation". doi:10.48550/arXiv.2202.01854.*
135. ^ *Rosas FE, et al. "Software in the natural world: A computational approach to hierarchical emergence". doi:10.48550/arXiv.2402.09090.*
136. ^ *Harte J, Umemura K, Brush M (2021). "DynaMETE: a hybrid MaxEnt-plus-mechanism theory of dynamic maroecology". Ecology Letters. 24: 935–949. https://onlinelibrary.wiley.com/doi/10.1111/ele.13714.*

137. ^*Harte J, Brush M, Umemura K, Newman EA (2024). "Dynamical theory of complex systems with two-way micro-macro causation". PNAS. 121: e2408676121. https://www.pnas.org/doi/10.1073/pnas.2408676121.*
138. ^*von Weizsäcker CF (1988). Aufbau der Physik. dtv, Carl Hanser Verlag, München, Wien.*
139. ^*Thiel F, Mualem I, Kessler D, Barkai E (2021). "Uncertainty relation between detection probability and energy fluctuations". Entropy. 23 (5): 595. doi:10.3390/e23050595.*
140. ^*Memmi D (2016). "Comparative foundations of Eastern and Western thought". AI & Soc. 32 (3): 359-368. doi:10.1007/s00146-016-0656-5.*

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