Why the world is flat, why we live in the Matrix, and other uncanny results from modern physics

Rolf R. Hainich

Currently the visible horizon of the universe (Hubble radius) equals its Schwartzschild radius, e.g. our universe has the same radius as a black hole of identical mass.
This is a most peculiar coincidence, because if the universe expands as being currently assumed (big bang model), this could only be true for one single moment in the history of the universe. On the other side, the coincidence is too unlikely as well as exact to be easily ignored. We review some papers that offer possible explanations.
In the second section, we review some papers about entropy, the holographic principle and quantum computers. We argue that the problem of vastly increasing entropy for matter that falls into a black hole only arises from the use of quite different definitions of entropy and that it vanishes if any entropy is generally taken as potential information in position space. We further argue that due to the higher degree of complexity inherent to quantum information, a 2D quantum space is at least as complex as a deterministic 3D space, hence the holographic principle does not really reduce what we perceive as 'degrees of freedom', but in the contrary, the quantum uncertainty that leads to the dimensional reduction is all the same essential to the concept of free will.
We further argue about black hole growth and decay speeds and get to speculate about black hole in/output as a serial process, with implications for information retention, and cosmology.
We conclude with some remarks about possible origins of the universe.
This paper is mainly intended as an enhanced review of current research and we strongly encourage to read trough the literature in the annex, most of it accessible by web links.

Shortly after Albert Einstein published his theory of General Relativity, Karl Schwartzschild calculated that a black hole has a radius or $R=2Gm/c^2$.
This Result has always since proven right, although it seems to be strange at a first glance, that the radius should be proportional to the mass (for everyday objects, it's the volume).
A black hole with the mass of our sun ($2x10^{30}$ kg) would have a radius of about 3 km. Pretty small but not strange.
However, what would be the radius of a black hole with the mass of the entire universe ? There we get about 14 billion light years, which is just the radius of the observable universe as we know it from astronomy. Pretty strange. Is the Universe in the end a black hole ?

Could one perhaps say that every physical entity that is self contained and separate, like a universe, or a black hole, has to comply to black hole physics, e.g. has a border that equals a black hole event horizon ?

If Big Bang theory is true, this can only be an accidental coincidence, because to keep that relation intact, the universe's mass would have to grow with time, or c or G would have to change, all of which hasn't been found so far..

Another argument against the black hole analogy is that black holes radiate (according to Stephen Hawking, 1974), but the background radiation e observe is 10^9 times hotter than what we would expect of an event horizon of universe size. That's however not really catching, because what we see there is not the true horizon but the echo of the universe's luminosity when it was just turning from opaque to transparent. We can't see behind that, so we just couldn't see the true horizon, which might be much cooler.

It is anyway obvious that there are still unsolved problems with the big bang model.

Some more of these are:

- The current paradigm of inflationary expansion states that the universe started from a tiny dot $^1/_{100}$ the size of a proton, that suddenly expanded (one could say exploded) in space as well as concerning its mass, by a whopping factor of 10^{60} in a very short time. Not really obvious why this actually had to happen, even though inflation basically arises as one possible solution of Einstein's equations for General Relativity.
- We need the concept of 'dark energy' to explain the apparently again accelerating expansion, and there is, for example, something called the 'Pioneer anomaly', that has not yet been explained at all, even though hundreds of reasons have been meticulously examined [16].

Could it be that the universe does not really expand, but that some change in cosmic constants just gives the impression of an expansion, or could it be that some change of mass or other parameters just keeps the horizon radius equal to a Schwartzschild radius ?

Another hint towards black hole analogies comes from "pre big bang" models in string theory [19],[25,[26].
There, one big bang scenario starts from a very old and vastly expanded universe, in which all black holes (and also stars) have evaporated (>10^{70} years old) and that is therefore filled only with a very thin, cold quantum gas. The theory goes that this could eventually contract again until some black holes form again. According to calculations, any such black hole could start a new universe, by exchanging space and time coordinates;

hence, multiple universes would be started. However it requires some belief that theory should not care for the actual mass involved...
Quite remarkable that in this theory, the universe would already have started as the 'inside of a black hole', which could also fuel the horizon analogy.

The coordinate swap is something known for long from Kruskal coordinates, that describe the inside of a black hole and do such an exchange. These coordinates manage to resolve the first singularity in the Schwartzschild solution (that one at the horizon), but it's still questionable if the results obtained are physical, or just a mathematical curiosity.

Definitely they lead to logical contradictions, at least with classical logic: an astronaut falling into a black hole is killed at the horizon for an outside observer, yet leading physicists insist there must be a reality of her own where she falls through the horizon almost unaffected !

Nonetheless, maybe some reasoning from classical General Relativity could help with the theories discussed:

> Classical General Relativity tells us that at the horizon, time must stand still, for an outside observer. Hence if the universe would collapse, matter falling into a black hole would 'freeze' just at the horizon for all time. Eventually, all remaining matter as well as other black holes would converge into one giant black hole, with all matter still just frozen at the horizon. For the 'inside', no time would have passed.
> So all available matter would have available any amount of time to merge into one giant black hole before anything attributed to the 'inside' could actually start to happen. The difficulty to explain how and why smaller black holes should form new universes would be avoided.
> If we, after all this has been accomplished, flip coordinates and switch to the inside, a something that could be a new universe would maybe start right then, with all the matter of the former universe and with a shiny, all new timescale.

Still if we see the theories discussed in the light of the black hole analogy, we have problems with the expansion of the universe, or we must assume that some quantities believed to be constant, are not really that constant...

Antonio F. Rañada for example [21] claims that according to General Relativity, the gravitational potential of a location influences the flow of time as well as the local speed of light.

Einstein already in 1912 and again in 1917 [22] came to the conclusion, that due to the mass in the universe, there must also be a cosmic 'background potential' that influences all clocks in the universe.
If this holds, as the universe expands the higher mass density in early times must also have caused a stronger background potential. Hence, all clocks must back then have gone slower. Light that we receive from there would then have an additional redshift due to this effect. It would be the same kind of redshift that we perceive with light from the proximity of a black hole, not the one that results from relative speed.

The effects are however similar in a sense: speed has the same implications as a gravitational potential (which is a function of v^2, where v is the escape speed form a gravitating object). Hence, there must also be a limit for the gravitational potential at v=c, e.g. at an event horizon.
Looking back in time, and towards the cosmic horizon, would then at least partly be like looking into a black hole, e.g. down the gravity potential.

Rañada's calculations show that the change in background gravitational potential and the resulting increase of clock rate alone could explain both the Pioneer anomaly and the observed 'acceleration' in the universal expansion.

There are also theories that result in a stationary universe:

Antonio Alfonso-Faus for example [10], [11] writes that the answer could be in a decrease of the Planck length with time. In this regime, the entropy of the universe would grow with time, as would its apparent size and its total mass.
One could perhaps speculate about a beginning not like a big bang, but like the development of an organism from a single cell, that divides myriads of times until our present state with 10^{120} Planck 'cells' is approached.
Alfonso-Faus also claims his theory explains both accelerating expansion and the Pioneer anomaly (as meanwhile do several other theories).

In conclusion, there are possible explanations some of which we have mentioned, but not yet a complete solution to our questions.

About entropy

1972, Jacob Bekenstein suggested that a black hole has an entropy that is ¼ its surface area in Planck areas (Bekenstein-Hawking entropy, see also [24]).
But what is entropy ?

Classical entropy is derived from thermodynamics and is really hard to determine for arbitrary physical systems. Black Hole entropy however, is exactly defined.
What is strange: Bekenstein-Hawking Entropy depends on the surface, which in turn is the square of the mass (as above, radius $R \propto m$, but Entropy $S \propto r^2$).
Thermal entropy however is roughly proportional to mass.
So the incredible growth in entropy for a mass falling into a black hole is peculiar and has drawn a lot of attention, but the real problem seems to be that these are entirely different definitions of entropy.

A possible explanation has been developed by C.F. v. Weizsaecker with his Ur theory, as early as 1954 (long before even Hawking made his calculations) and published in subsequent works [4]. The theory has almost been forgotten, but has been revived by the works of Holger Lyre [1],[2] and Anton Zeilinger [3].

The quintessence is, that thermal entropy ignores spatial information, while black hole entropy is all about it. Even more: Caslav Brukner and Anton Zeilinger [3] have also recently pointed out that black hole entropy is equal to the potential information in quantum information theory. It can entirely be defined in position space, because all physical properties can be expressed as (converted into) positions.
Ur theory concludes that the entropy of the universe is the cross section of the universe in Planck units. That is exactly the black hole entropy, because the cross section of a 3-dimensional sphere is exactly ¼ of its surface area.

The wondersome entropy increase of a mass falling into a black hole would hence be not peculiar at all, indeed if we don't change paradigms in the course of calculation, actually nothing happens at all.
However, again we get a number that goes with r^2, or m^2.
Wouldn't we, in a 3dimensional position space like our universe, expect something like r^3 ?

This peculiarity led Gerard 't Hooft [5],[7] and Leonard Susskind [6] to the suspicion, that the world we know behaves like a hologram, e.g. all reality could as well be depicted as a projection on a 2-dimensional screen, that equals the boundary area of a volume. It has even been shown that under certain conditions, physics can be described in a basically 2-dimensional set of equations.

Does this mean that 3 d space is an illusion ? I guess not, because

1) the surface area has such an incredible number of 'excess' bits to describe reality, that it really won't matter for everyday experience if the world could also be described in 2 dimensions (the entropy of a single proton is already 10^{40} bits), and
2) the entropy numbers given have been derived using methods of quantum theory, which impose some 'unnormal' constraints on the results obtained. This has been shown very elementary and obvious in the works of Y. Jack Ng [8],[9], who derives exactly the same entropy as in Ur theory, with a principally identical ansatz, but explicitly shows that the restriction to 2 dimensions arises due to the fact that all spatial information underlies the uncertainty relation according to Heisenberg. An even more astonishing result was published by Jia-Zhong Chen and Duoje Jia [27], just while this paper was finished. The authors take the theory backward and derive the uncertainty relation from the holographic principle.
   Maybe some further reasoning of this kind could also shed a light onto nonlocality ?...

Hence, the holographic principle just arises from the fact that the world is not deterministic.
If the world was deterministic, maybe entropy would result in much larger numbers, according to a 3d position space.

The theories discussed lead to a peculiar apprehension of reality, but taken together, they seem to make a deeper sense:

> Quantum bits can represent a much higher complexity than conventional bits. It has been shown that quantum algorithms could compute certain problems with only a linear increase of computation time vs. complexity, where conventional algorithms exhibit an exponential increase. It has also been known for long that the simulation even of simple quantum systems with conventional computers soon leads to an overwhelming complexity.
>
> The holographic 2D representation of the world in quantum bits might therefore allow for at least the complexity and the degrees of freedom like with a 3D deterministic representation.
>
> One should remember that In a deterministic world, everything is predetermined from beginning to end. Particularly, there is no free will possible in such a world. One could argue for aeons what free will essentially is, and if it really exists, but that does not change the fact that it does not exist in pure determinism

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> The remarkable conclusion is, that while the holographic principle at a first glance seems to define us as mere shadows acting on a projection screen, we learn from further reasoning that this by no means restricts anything.
> In the contrary, if it weren't this way, we would be nothing but dentwheels in an eternal, perfect and *essentially dead* clockwork universe.

Another conclusion from the mentioned papers is, that the universe equals a quantum computer with approx. 10^{120} bits or qubits.

Recently the question appeared in the media, if we live in a 'Matrix', and, even more so, if we could detect this by discovering 'software errors' with physical experiments.

Well, we surely won't see a 'bluescreen' in the sky one nice day (that blue has different reasons), but in a sense, the universe IS a computer, namely a quantum computer, but not in the naive context that it would run deterministic programs like a Turing machine.
It works with a few initial parameters and probabilistic 'algorithms' that happen to result in a world of astonishing complexity.
While this paper was written, a very good article appeared in Scientific American [31].

Parallel or serial ?

Intuitively, the black hole computer appears to be a parallel device. Some aspects however turn out in a different way. This concerns feeding and evaporation of black holes, e.g. the 'input' and 'output of the black hole computer :

> Feeding a black hole leads to a mathematical peculiaritiy:
> As mentioned, the radius is $R = 2Gm/c^2$. This looks as if a black hole is essentially one dimensional: It behaves, related to mass acquired, like a pile.

A literature search showed that Bekenstein and Mayo had already developed the idea of a one dimensional BH information channel [28],[29], from different reasoning mainly based on entropy considerations.

Consider that particles having fallen into a horizon are frozen in time. Adding more particles may not necessarily move them any more, even though the horizon expands by 1 Planck length for every new particle. This could lead to a geometric model of particles forming a new onion like shell each by each, if we also speculate about some form of non locality. This may be less insane than it first appears: Newer simulations on the apparent size of a BH horizon to an infalling observer lead a constant angular size under certain conditions. Which in turn can be interpreted as the horizon shrinking all the time, e.g. becoming a point when the observer approaches it. This way the horizon could become factually identical to the singularity. This could, maybe, open a way to explain the famous paradox between the realities of the infalling and the remote observer.

The horizon as a point – really peculiar. The holographic principle tells that entropy bits might be evenly distributed over the horizon as the entropy is A/4, according to Hawking.
This however is only a visualization, of a mere number, and as we have already stated, that the cross section may be a better candidate.

One also could perhaps draw some link to the non locality problem in quantum physics: If we suppose all quantum elements of the "surface" to be entangled, affecting ("measuring") any of them would affect all, immediately. This is very speculative and one can argue that the violent physical interaction in BH formation leads to ultimate decoherence, but the problem may lead to astonishing conclusions anyway.

We could also even speculate whether the sequence of quantum units is changed or unchanged between acquisition and evaporation, e.g. if maybe particles entering a black hole would later get out in inverted sequence like with a last in / first out device (something called a stack in computer science).
This is a far fetched assumption, but interesting because it arises some implications on the question if information could reappear out of a black hole: even if thermal evaporation emits particles at random times, an unchanged particle sequence could retain a lot of information.

Black hole decay and growth

These calculations are from 'classical' quantum theory and may need huge corrections for small masses if results from string theory are verified. But let's give it a try:
In quantum theory, the smallest possible black hole would be one with Planck mass (10^{-8}kg). It turns out that this one has a radius of about 2 * Planck length (10^{-34}m). Planck length is the smallest measurable distance, and such a black hole would be the smallest confined entity imaginable.

According to Stephen Hawking, a black hole emits thermal radiation, thus losing energy and 'evaporating' after some finite time. The evaporation time of a 'normal' black hole is

extremely long, but for the Planck black hole, we get the result that it would evaporate in Planck time (10^{-46}s) and emit an amount of energy of 10^{28}eV, that resembles 60 kg of conventional explosives.
Would we try to 'feed' it with enough matter as to prevent its evaporation, we would have to throw in 400,000 times the mass of our sun in one second, causing an energy outbreak that would make a supernova look like a firefly.
(A black hole would be an ideal matter/energy converter, but these numbers let the mere idea of it appear entirely horrible).
How fast can a black hole grow ?
One might argue that the radius is not material, only a horizon, and could therefore grow faster than light. A horizon however is just about space curvature, e.g. gravity, and Einstein's main reason to develop General Relativity was to remove the problem that light could travel no faster than c but in the Newtonian sight, gravity apparently could.
GR should therefore not allow the horizon to move faster than light.

We could also argue that for an outside observer, matter falling into a black hole never passes the horizon, e.g. stays there, and if we feed the BH too fast, the horizon, including that matter, would approach us faster than light.

The uttermost amount of mass per time that could be fed into any black hole of any size would therefore be ($\partial R/\partial t < c$) : $\partial m/\partial t < c^3/2G \approx 2.25 * 10^{35}$ kg/s

This is approx. the evaporation rate of a quantum sized black hole. It is a little smaller than the feed rate calculated to maintain a Planck mass black hole, but exactness can anyway not be expected with these numbers because when approaching Planck size we deal with approximations.
Hence, this tells us that the shrinking rate of an evaporating BH's horizon just approaches c at the very last moment.

There is also another, usually much lower limit on BH growth however. It has to do with radiation pressure. A rotating BH (any real BH will rotate, as matter will only be accreted spiraling into it in a so called accretion disk), will swallow only 58% of everything approaching it, the rest (42%) will directly be converted to energy and emitted as radiation.

Radiation pressure imposes a limit on accretion (Eddington Limit) of roughly

$$\partial m/\partial t_{Ed} = L_{Ed} \approx 1.5 * 10^{14} M_{BH}/M_{\odot} \text{ kg/s}$$

(there are tons of literature with more exact derivations, still an unfinished issue)

This is far less than our absolute limit from above, for any BH currently existing. A short calculation reveals that at about 1/100 the mass of the entire universe, the Eddington limit approaches the absolute growth limit. The absolute limit would therefore only get important in the scenario of a 'Big Crunch'.

The absolute growth limit also has some implications if we look at the peculiar coincidence that the radius of the universe equals the radius of a black hole with the same mass:

If that were more than just coincidence, then the expansion could only occur if the mass of the universe would grow at a rate of at ≈ ½ Planck mass per Planck time all the way long (because the horizon grows just with speed c).
There is some similarity in this with theories like that of Alfonso-Faus [11], but with a variation of M instead of $\hbar$.
This idea will also definitely provoke a huge veto from most of the scientific community, for good reasons, but given the mentioned problems with inflation, and given the fact that the coincidence is not yet well explained.....

(A final word on this crackpot idea: A continuos appearance of new particles should be possible to detect. However, the energy flow involved would 'only' be about $3.63*10^{52}$ Watts. This would (very roughly) equal $1/10^4$ times the energy flow of the cosmic background radiation (which has a temperature of about 2.9 K). Such an energy flow may in principle be difficult to detect, but the single particles crated could have very high energies).

Some thoughts about the origin of the universe:

One question that has bugged physicists all the time, why are universal constants (e.g. the cosmological constant), apparently fine tuned as to result in a maximum amount of complexity arising in the course of development.

We have already cited a cyclical (pre-big bang) model from string theory. However, such a model may explain characteristics of the current cosmology, but still there is no beginning, and this would violate our usual understanding of causality. Yet, any beginning of 'everything' also does.

Aristotle (and my grandma) said 'from nothing comes nothing', without giving any reasons. Quite the contrary could be more logical: the concept of nothing has the huge advantage that there can't be any causality. Causality only arises when at least 2 different entities

react with each other, resulting in cause and effect, e.g. a chain of events. No events, no causality. No causality, no conservation laws. [1]
Hence from nothing, everything could suddenly arise. For example, a universe in its initial state.
More subtle models involve the same tricks as in inflationary expansion [17],[18], but to me, arguing that "the total energy of a Robertson-walker universe is zero" is hardly better in the light of classical conservation principles than just dropping causality.

But why is our universe the way it is, e.g. apparently so perfectly tuned for the development of life?
Explanations have been developed, one being the 'anthropic principle': There may be many universes, but ours is like it is because if it wasn't, we weren't here. Naive commentators sometimes say this resembles the geocentric world view of the sinister medieval. But it doesn't, because the anthropic principle doesn't make us special at all.
The second and third reasoning are in a sense similar: Either a very advanced civilization has started the universe, or God did so. In both cases, the reason why it is like it is, doesn't pose further questions. One could even speculate so far as to assume, that some civilization might first have arisen from a barren universe that only accidentally and with difficulty brought forth life, then they discovered a method of starting universes (inflation theories would require only small amount of energy to do this) and optimized that for better convenience. But that's stuff for science fiction.

If the physical theories providing some possibilities for this are true or are not, will still take a long time to find out.
The fourth possibility is that the universe can't be any other way than ours, only we have as to now been unable to see the reason why.

Corrections for very small masses

String theory predicts some corrections to the formula for very small masses (mainly because it introduces extra dimensions, which can lead to *huge* corrections, so the calculations we did for quantum black holes using classical quantum theory, may be way

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[1] Only systems consisting of at least 2 basic building blocks (quanta, qubits, strings ?) coupled by something we call space (or maybe entanglement ?) could form a causal, self contained system, hence a 'something' in contradiction to 'nothing').
Any number of particles without this kind of linkage would just be singled out in a necessarily infinite, forceless and pathless 'space' of nothing. Speaking of their mere existence would be nonsensical due to the absence of any reference and any field to transport any information or forces.

off from the real thing), and gives rise to the possibility, that tiny black holes could form at energies of only a few TeV (10^{16} times less than the Planck black hole we just examined). Loop Quantum Gravity theories (coming in several varieties), get to quite similar predictions..

Such energies are still beyond the scope of present colliders (<1TeV being the limit of Fermilab), but the LHC (Large Hadron Collider), currently being built at CERN in Geneva, will get to about 8 TeV, and if the theories are right, black holes would form in it by the numbers [12],[13],[14],[15],.

Hence, the LHC might provide what has been missing: some first experimental evidence for string and other advanced theories. In about 3 years we will know more

Could such micro black holes then grow to a size that it would swallow our planet ?

Most surely not, because the necessary supply of matter to keep them from evaporating would still be impossible to inject against the resulting incredible energy outbursts and, as cosmic radiation is still many magnitudes more powerful than anything we can produce, micro black holes should already have been produced by it all the time, obviously without any bad effects at all.

Rolf R. Hainich

v.3.1 May, 2005

Some numbers and equations

light speed $c = 3*10^8$ m/s

Gravity constant $G = 6 * 10^{-11}$

Planck constant $\hbar = h/2\pi = 1.05*10^{-34}$ ws

Planck mass $m_p = 2.2*10^{-8}$ kg

Planck energy $e_p = m_p c^2 = 10^{28}$ eV = $1.96*10^9$ ws

Planck time $t_p = 5.4*10^{-44}$ s

Planck length $l_p = 1.6*10^{-34}$ m

Mass of our sun $m_\odot \approx 10^{30}$ kg

Black hole life expectancy $T_{BH} = G^2 m^3/\hbar c^4$

'Black hole computer' clock $t \approx Gm/c^3$

Smallest possible black hole: $Gm/c^3 = G^2m^3/\hbar c^4$, $\hbar c^4 \approx 1$, $m_{BH} \approx m_p$, $T_{BH} \approx t_p$, $R_{BH} \approx 2*l_p$

Feeding Smallest possible black hole to stay: $m_p/t_p \approx 4*10^{35}$ kg/sec ($\approx 4*10^5$ solar masses per second!)

$\Rightarrow$ micro black holes will never suck up a planet, radiation pressure will blow away everything.

Energy of smallest Black hole: $E = m_p c^2 \approx 10^{28}$eV $\approx 2*10^9$ ws $\approx$ 60 kg mineral oil (or conventional explosives).

However: black hole formation according to string theory at $>\approx 10^{12}$ eV $\approx 10^{-24}$ kg of conv. explosives.

Universe mass: $\approx 10^{11}$ galaxies of 10^{11} suns @10^{30}kg, $*10_{(\text{dark matter,energy})} \approx 10^{53}$ kg

Universe black hole radius $R=2Gm/c^2 \approx 1.3*10^{26}$ m $\approx$ 14 billion light years

Ultimate growth limit of black hole radius:

$$\partial R/\partial t < c \;\Rightarrow\; \partial m/\partial t < c^3/2G \;\approx\; 2.25*10^{35} \text{ kg/s} \;\approx\; \tfrac{1}{2}\, m_p/t_p$$

Eddington Limit: $\partial m/\partial t_{Ed} = L_{Ed} \approx 1.5 * 10^{14}\, m_{BH}/m_\odot$ kg/s

Boltzmann Constant $\sigma = 2\pi^5k^4/15h^3c^2 = 5.67051*10^{-8}$ W/m^{2}K^4

Radiation power (area A, temperature T) $P = \sigma AT^4$ W

Rest mass of a proton: $9{,}383*10^8$ eV = $1.6726*10^{-27}$ kg

Rest mass of an electron: $8.856*10^{-31}$ kg

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http://www.sciamdigital.com/

Further reading

Michael A. Nielsen, Isaac L. Chuang: Quantum Computation and Quantum Information
Cambridge University Press (September, 2000) ISBN: 0521635039

Eleanor G. Rieffel, Wolfgang Polak: Quantum Computation for non Physicists
http://www.arxiv.org/abs/quant-ph/9809016

Brian Greene: The Elegant Universe; ISBN: 0375708111
(a popular introduction to string theory)
http://www.pbs.org/wgbh/nova/elegant/
(the website offers supplement materials to the book and the whole DVD content online)