Article

Open World of Quantum Cosmology

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Abstract

An open worldview is discussed with respect to $ER = EPR$ [1]. Quantum states are generated by a quantum error correction code with an ancillary Hilbert space assigned to the black hole interior. These result in the violation of the Bekenstein bound and the formation of firewalls. In the open world these generated qubits are assigned to nascent cosmologies by means which involve hypercomputation. An exterior observer is not able to access these computations directly, but there are quantum statistical consequences of this process. Exterior quantum states will have a departure from Hawking radiation as coherent laser-like states.

1 Horizons, singularities and entanglement

General relativity (GR) and quantum mechanics (QM) share some similar properties with respect to entanglement and causality connectedness by Einstein-Rosen bridges in black holes. The connection between GR and QM has other such connections, such as supersymmetry[2], holography[3] and the AdS/CFT correspondence[4]. GR and QM appear to have similarities or equivalencies. The main difference that exists between the two is that QM is governed by unitary transformations whereas GR is governed by hyperbolic transformations and Bogoliubov operators. The orbit space in QM is elliptic while GR is hyperbolic. Quantum physics is closed, while spacetime physics is open dynamics, such as the accelerated expansion of the observable universe expands eternally.

A black hole emits Hawking radiation produced from entangled pairs in the vacuum. As such Hawking radiation has entanglement with the black hole all through the quantum decay process. Eventually the black hole has more entanglement information than permitted by the Bekenstein-Bousso bound. This means that one must permit some form of black hole remnant that can quantum decay to the Planck scale, or that something happens to the black hole so it no longer can take in information or become entangled with radiation. In this case the black hole has in a sense run out of entanglement so the horizon becomes a region of discontinuity. This firewall implies the equivalence principle (EP) fails. If could be that Hawking radiation that is emitted later on is entangled with earlier Hawking radiation. This could prevent the explosion of entanglement information in the black hole. However, this violates quantum monogamy.

Quantum monogamy assumes a certain closed nature to quantum information, and here it is proposed this may not be entirely correct. The decoherence model of QM and classicality is suggests this as well. The connection between GR and QM may require an open world view, where QM from a closed perspective appears irreversible. A more modest requirement is the world is not a closed system, and in particular that black holes are not closed. This means that entanglement monogamy is not an entirely certain. A more general form of nonlocality may mean that entanglement of a state may be uncertain, and a bipartite entanglement and tripartite entanglement may exist in some nonlocal form of uncertainty. This may connect with black holes, such as the suggestion black holes generate nascent universes [5]. This essay explores this possibility.

In [6] are singularity theorems for black holes and dS/AdS spacetimes. This may be contrasted with connections between entanglement and distance [7]. Let a spacelike surface $\mathcal{S}$ slice through a dS/AdS spacetime, a black hole interior and a Minkowski spacetime asymptotic region $\mathcal{M}$. Let $\mathcal{S}$ contain a trapping region $\mathcal{T}$. The black hole interior is an Einstein-Rosen bridge which connects dS/AdS and $\mathcal{M}$.

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Consider the two regions C and D with $C \subset \mathcal{T}$ the trapping region or $C \subset I^+(\mathcal{T})$ and D in $\mathcal{M}$. If C is in the time evolved region from $\mathcal{T}$, or $C \subset I^+(\mathcal{T})$, this is in the evolute of $\mathcal{S}$. The mutual information between these two regions is

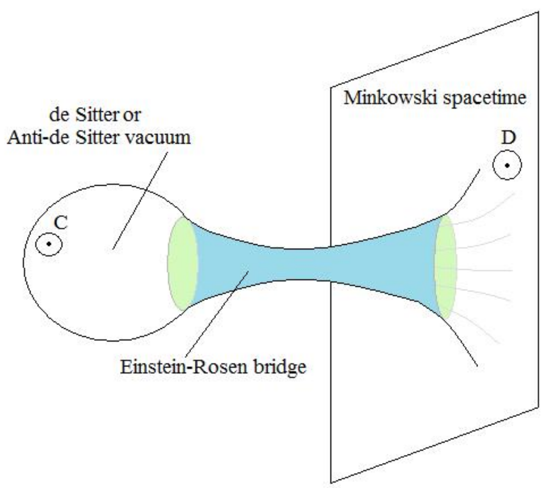
$$I(C,\ D)\ =\ S(C)\ +\ S(D)\ -\ S(C \cup D), \tag{1.1}$$

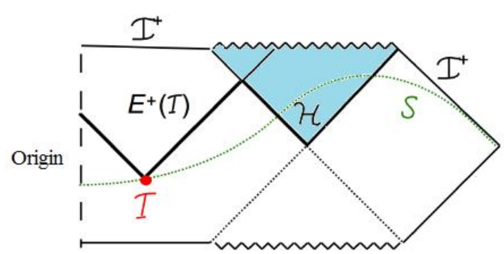
with $I(C,\ D)\ \geq\ 0$. This is an upper bound on quantum correlations between systems. For the operators Ω_C and Ω_D in C and D the mutual information is

$$I(C,\ D)\ \geq\ \frac{(\langle\Omega_C\Omega_D\rangle\ -\ \langle\Omega_C\rangle\langle\Omega_D\rangle)^2}{(2|\Omega_C|^2|\Omega_D|^2)}. \tag{1.2}$$

The correlation $\langle\Omega_C\Omega_D\rangle$ is dependent upon an interaction or two point function between the two regions and so $\langle\Omega_C\Omega_D\rangle\ \sim\ G(x_C,\ x_D)$. For a long range interaction $G(x_C,\ x_D)\ \sim\ |x_c\ -\ x_D|^{2\ -\ D}$ for D the dimension of the spacetime, or for a massive field theory this may be $G(x_C,\ x_D)\ \sim\ e^{-|x_C\ -\ x_D|}$. Quantum correlations give a proper distance between two regions.

The Penrose theorem assumes, a noncompact Cauchy surface $\mathcal{S}$, null convergence conditions and the existence of a trapped surface $\mathcal{T}$, where the future development $E^+(\mathcal{T})\ =\ \partial I^+(\mathcal{T})$ null geodesics is incomplete. Hence at least one geodesic on $E^+(\mathcal{T})$ must terminate on a singularity. In [6] considers horizons $\mathcal{H}\ =\ \partial I^+(\mathcal{I}^-)$, where each connected part is an individual black hole horizon and $\mathcal{I}^-$ past infinity. If $\mathcal{T}$ is not contained in $\mathcal{H}$ the future of $\mathcal{T}$ is bounded by an noncompact achronal region and $\mathcal{T}\ \subset\ \mathcal{H}$ if we have no naked singularities. If some black holes with horizons in $\mathcal{H}$ never cross $E^+(\mathcal{T})$ then $\mathcal{E}\ =\ E^+(T) \cap \mathcal{H}$ is multiply connected. The horizon either extends all the way back to the initial singularity at $\mathcal{I}^-$, or contains multiple connected components. If the first class is not empty then $\bar{\mathcal{E}}$ is noncompact and the generator extends to the infinite future, and this boundary means $\bar{\mathcal{E}}$ is not a complete achronal surface. The two classes of generators may be joined so the two are defined by some set of generators so that $t(g)\ \rightarrow\ t(g) =\ \tau\ \rightarrow\ \infty$ so the boundary at τ would be noncompact which is not permitted.





This necessarily divides $\mathcal{H}$ into connected components of the first and second type and the two conditions are contradictions. The Einstein-Rosen bridge is connected to an arbitrary number of black holes and there can then be the relationship between entanglement and black holes states that is a multiple set. This implies that the quantum monogamy condition is in general not correct.

2 Quantum error correction

Maps between a pure vacuum $|0\rangle$ in a Hilbert space H_M and the pure boson state $|i\rangle$ for a black hole of mass M to a BH of mass $M - E_n$, with the Hilbert space $\oplus_n H_{M-E_n}$. This state space has a dimension given by the integer partition of N. These operators give the unitary maps from $|i\rangle|0\rangle \rightarrow |j\rangle|n\rangle$ with

$$|i\rangle|0\rangle = \sum_{n,j}^{i} C^i_{n,j}|j\rangle|n\rangle. \tag{2.1}$$

The details of the operators $C^i_{n,j}$ are unknown, but the entropy of these operators on a coarse grained is

$$\sum_j \langle j|C^\dagger_{k,n}C^i_{k,m}|k\rangle = C^\dagger_n C_m \simeq e^{-E_n\beta}\delta_{mn} \tag{2.2}$$

The growth and decay of a black hole is a quantum transition. The process involves a Hamiltonian for the black hole, the radiation emitted as some interaction Hamiltonian that couples the two $H = H_{bh} + H_r + H_{int}$. The interaction Hamiltonian gives a unitary operator $U(t) = exp\left(i\int^t H_{int}\right)dt$, where $t < t_p$ for t_p the page time. The states for the black hole plus radiation in the early phase are $|i\rangle|0\rangle$ that is mapped into $|j\rangle|n\rangle$ here $|j\rangle|n\rangle$ and $|0\rangle$ are in H_{bh} and $|0\rangle$ and $|n\rangle$ are the microstates of the black hole and radiation respectively.

$$\rho = \sum_n w_n|n\rangle\langle n|,\ w_n = \frac{e^{-E_n\beta}}{Z} \tag{2.3}$$

with $Z = \sum_n e^{-E_n\beta}$ and $\beta = 8\pi M = \beta$ and $dim(H_{M-E_n}) = E_n = Ne^{-E_n\beta}$. The entropy by their Hilbert spaces H_b and H_r is

$$dim(H_b \oplus H_r) = \sum_n dim(H_{M-E_n}) = NZ, \tag{2.4}$$

which exceeds the Bekenstein bound.

The unitary evolution,

$$U|i\rangle|0\rangle = \sum_n |i\rangle|n\rangle \tag{2.5}$$

with $U^\dagger U = 1$ implies

$$\sum_{n,j} C^i_{n,j}C^{k*}_{n,j} = \delta^{ik},\ \sum_n C^\dagger C_n = \mathbb{I}_M. \tag{2.6}$$

The trace of the density matrix $\sum_{n,j} C^i_{n,j}C^{k*}_{n,j} = \delta^{ik},\ \sum_n C^\dagger C_n = \mathbb{I}_M$ defines the matrix elements

$$\sum_j \langle j|\rho_{nm}|j\rangle = \sum_j \langle j|C_n|i\rangle\langle i|C^\dagger_m|j\rangle = \langle i|C^\dagger_m C_n|i\rangle = e_n^{-E_n\beta}\delta_{mn}. \tag{2.7}$$

The diagonal elements with $n = m$ contains $Ne^{-E_n\beta}$ terms. The unitarity condition gives $1/N$ times this and the result is then $e^{-E_n\beta}$. Off diagonal portions are equally numerous, but the phases are considered to be random, approximately similar to spontaneous emission. A detailed analysis of the phases is more complex, but that is a part of what we may be able to do for a set of coherent histories. This term is then equal in number, but the Poisson result for the statistical deviation of the phases gives a result that is $\sim 1/\sqrt{N}$ the diagonal result and may be ignored in a semi-classical limit.

We may now compare the new and old black hole. The new black hole has the BH and radiation R entropy equal $S_b = S_r$ and the joint entropy is zero with

$$I_{br} = S_b + S_r - S_{br} \tag{2.8}$$

with

$$S_{br} = 0,\ S_b = S_r = log(Z) + \beta\bar{E},\ I_{br} = 2S_b \tag{2.9}$$

for $\bar{E} = \sum_n E_n e^{-E_n\beta}$. The radiation is maximally entangled with the black hole and carries the thermal entropy. The mutual information is maximal and the joint entropy is zero, which is what changes over time as the black hole ages.

The older black hole is time evolved by the matrix element U so that

$$\rho(t') = U(t')\rho(0)U^\dagger(t') \tag{2.10}$$

where the initial density matrix is given by the Boulware and black hole states as $\rho(0) = (1/N)1_M|0\rangle\langle 0|$. The time evolved density matrix is then

$$\rho(t) = \frac{1}{N}U^\dagger(t)1_M|0\rangle\langle\rangle|U(t) = \frac{1}{N}\sum_{jk} C^i_{j,n}C^{*i}_{k,m} = \frac{1}{N}C_nC^*_m \tag{2.11}$$

The joint entropy is $S_{br} = log\ N$ in contrast to $log(NZ)$ which is in line with the Bekenstein bound. The entropies are then

$$S_b = log(N) - \beta\bar{E},\ S_r = log(N) - \beta\bar{E},\ S_{br} = log(N),\ I_{br} = log(Z) \tag{2.12}$$

which is the state of the old black hole.

This is where quantum error correction codes enter the game. The code operates on a code space H_c and has a set of basis elements $|i_c\rangle$. The dimension of the code space is $dim\ H_c << N$, which insures that errors which occur in the system are corrected with fidelity. However, as errors are corrected the coding space grows. By this it is meant that the number of nonvacuum states increases. The code space holds transfered information so that unitarity is conserved. While the code space is "virtual"the entropy associated with it is physically real and contained in the black hole. Once the entropy grows to N the Bekenstein bound is no longer applicable. This is a manifestation of the fire wall problem.

3 Quantum computing an open world and singularities

A black hole that rotates or is charged the spacelike region in the interior is no longer bounded by a singularity. The spacelike trapping region past the outer horizon contains an additional horizon that leads into a timelike region with a singularity. The horizon that separates the spacelike region, type II region, from this further timelike region type III is a Cauchy horizon. This horizon accumulates geodesics, which is singular blue shifting of radiation. This is also found with Malament-Hogarth spacetimes that solve hyperarithmetic problems [8][11]. The asymptotic time compression on Cauchy horizons in M-H spacetimes permits super-Turing machines.

The M-H spacetime has a blue shifting of light on the Cauchy horizon for all radiation that enters the BH. An observer may witness an infinite amount of quantum information in a finite time. This is a divergence problem, which may be parameterized by a divergent momentum in a propagator. The basic rule for quantum propagators is

$$\frac{1}{\sqrt{det(-\nabla^2 + m^2)}} = exp\left(-\frac{1}{2}tr\ log(-\nabla^2 + m^2)\right). \tag{3.1}$$

The Schwinger parameter t the effective action for $H = p^2 + m^2 = -\nabla^2 + m^2$ is

$$I^* = \frac{1}{2}Tr\left(-\nabla^2 + m^2\right) = \frac{1}{2}\int_0^\infty dt\frac{exp(-tH)}{t} \tag{3.2}$$

The division by t reflects the rotation group for the diffeomorphism of the loop. Again at $t = 0$ this is terribly divergent. However, the Schwinger parameter is the ratio of two coordinates $\tau,\ \sigma$ for a string world sheet with $t = \tau/\sigma$. The interchange the time and spatial coordinates of the string world sheet is equivalent to exchanging the t and s channel. Therefore $t > 1$ is equivalent to $t < 1$, and we may write this integral with the lower value a unit rather than zero,

$$I^* = \frac{1}{2}\int_1^\infty dt\frac{exp(-tH)}{t} \tag{3.3}$$

which is a finite integral. This is QFT with a cut off at the $t = 1$, without any artificial cut off condition that manifestly demolishes locality.

The cut off in scale means that self-similar processes that can give rise to hyper-computation can be thought of as a standard Turing machine process plus a dual part that is removed from the scale observation. The relevant physics has locality only to some minimal distance in spacetime. These cut-offs in locality correspond to short distance singularities. From a computational perspective the UV divergence is the time compression of an algorithm in an MH spacetime and generically is of the form seen in [8]. The type of algorithm is infinitely recursive, but the breakdown of locality is seen as a sort of computational horizon. The locality cut-off is the string scale, which for a propagator around a singularity or Cauchy horizon is

$$G(x,\ y) = \int_1^\infty d\tau\int\frac{d^4p}{(2\pi)^3}e^{p\cdot(x-y)\ -\ \tau(p^2\ +\ m^2)} = \int\frac{d^4p}{(2\pi)^3}\frac{e^{-p\cdot(x-y)}}{p^2 + m^2} \tag{3.4}$$

where Lorentzian metric is restored. The connection $(p^2 + m^2) \leftrightarrow exp(-tr\ log(-\nabla^2 + m^2))$ is then apparent

The metric for a blackhole is

$$s^2 = f(r)dt^2 - f^{-1}(r)dr^2 + r^2d\Omega_n^2$$

which for the Kerr-Newman black hole $n = 2$, and $f(r) = (r - r_+)(r - r_-)/r^2$. We examine this solution in the neighborhood of $r = r_-$. In the Eddington coordinates

$$u = t - r^*,\ v = t + r^*$$

where the tortoise coordinate r^* is defined by

$$\frac{dr^*}{dr} = \frac{1}{f(r)}, \tag{3.5}$$

and the line element in the Eddington coordinates is

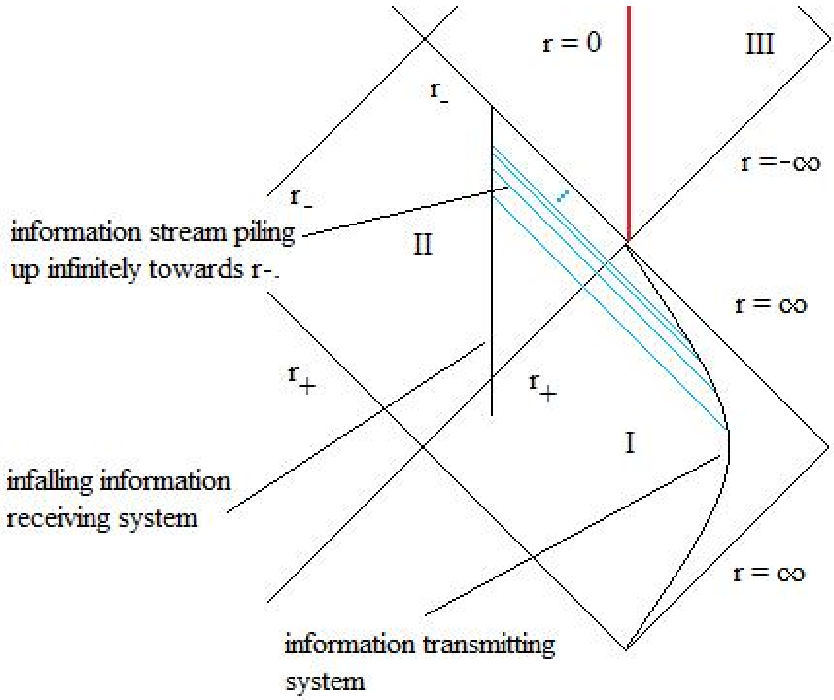
$$ds^2 = -f(r)dudv + r(u,v)^2d\Omega_2^2 \tag{3.6}$$

The tortoise coordinate between the two horizons is then

$$r^* = \int_{r_+}^r\frac{dr'}{f(r')} = \left(\frac{r_+^2\ ln(r' - r_+) - r_-^2\ ln(r' - r_-)}{r_+ - r_-} + r'\right)\Big|_{r_+}^r$$

which for r near r_- and $r_+ - r_- = Q = 2\sqrt{m^2 - a^2}$ is

$$r^* = \left(\frac{r_+^2(ln(|r - r_- + Q|) + i\pi) - r_-^2\ ln(r - r_-)}{Q} + r + \lim_{r\rightarrow r_-} ln\Big[\frac{(r - r_+)^{r_+^2}}{(r - r_-)^{r_-^2}}\Big]\right)$$



The solution diverges at the two horizons. A Turing machine that crosses the r_+ horizon will have an infinite tortoise coordinate distance at a finite $r > r_-$ and further from this point to the r_- horizon is also an infinite tortoise coordinate distance.

The tortoise coordinate distance from a point $r_+ > r > r_-$ to the inner horizon r_- is divergent. The metric term is

$$f(r) \simeq \frac{Q}{r_-^2}(r - r_-)$$

The tortoise coordinate for r_- near the horizon is $r^* \simeq -r_-^2\ ln(r - r_-)/Q$ and so

$$r - r_- \simeq e^{-Qr^*/r_-^2} \tag{3.7}$$

so that $r \rightarrow r_-$ in a divergent tortoise coordinate distance. The u and v coordinates diverge, which means the better coordinates are $U = e^{Qu/r_-^2}$ and $V = e^{-Qv/r_-^2}$. Within these Kruskal coordinates there is no divergence and the above divergence is seen to be a coordinate singularity.

The Killing vector K_t near the inner the inner horizon is $K_t = \sqrt{f(r)}\partial_t$, which is such that $\mathbf{p} \cdot K_t = const$. The vanishing of the Killing vector near the horizon indicates that the momentum vector must diverge at that point. This means that the momentum four vector varies as $1/\sqrt{r - r_-} \simeq e^{-Qr^*/2r_-^2}$. We may then make an estimate of the information content. We may sum these momenta between increments the radius, or the radius per Planck length. In so doing we posit this momentum in carried by action of the momentum operator on a field operator or quantum wave function $P_{op}\phi = \pi$ as

$$\pi = \frac{e^{ik(t - r^*)}}{\sqrt{r - r_-}} = e^{ik(t - r^*)}e^{-Qr^*/2r_-^2}. \tag{3.8}$$

The summation of this over time is

$$\int_0^\infty \pi dr^* \ = \ 2\pi e^{ikt}\delta(k \ - \ iQ/2r_-^2). \tag{3.9}$$

The solution is infinite for $k \ = \ iQ/2r_-^2$. This means that in the spacelike region II $r_+ \ > \ r \ > \ r_-$ the information receiving system can receive an arbitrary amount of information. The occurrence at an imaginary valued wave number means from a quantum perspective with $k \ = \ \sqrt{E \ - \ V}$ that the solution occurs at a potential barrier with $V \ > \ E$. The inner horizon may then have some sort of physical content other than just a coordinate singularity.

We may then write the wave vector as $k \ = \ \sqrt{-\nabla^2 \ + \ m^2}$, which defines the propagator element $k^{-1} \ = \ exp(-\frac{1}{2}tr \ ln(-\nabla^2 \ + \ m^2))$. The inclusion of a potential function $V(r) \ = \ \{\mu \ > \ 0, \ r \ = \ r_-, \ 0$ $elsewhere\}$ corresponds to the mass of fields on r_-. It is at this barrier the wave vector corresponds to the $iQ/2r_-^2$. The free field in this region however is well described by

$$I^* \ = \ \frac{1}{2}\lim_{T\to\infty^-}\int_1^T \frac{dt}{t}e^{-tH} \tag{3.10}$$

which means a field is string-like and well behaved.

This potential barrier may be seen as a sort of wall created by the occurrence of all the matter which compose the black hole. All of the fields which compose the black hole fall in with a proper time or interval $\tau \ = \ e^{-Qr^*/r_-^2}/E$, where E is the energy of these particles. As the proper time approaches zero the timelike condition on geodesics approaches a null condition and the Lorentz boosted masses of the particles becomes enormous. Any approaching particle encounters r_- at the same time proper time $\tau \ \to \ 0$ and there is a large material barrier encountered. This is then a sort of delta function potential centered at r_-, with matter-waves glued to this surface.

We may then propose that with the action I^* corresponding to an MH-spacetime, or super-task, that it is possible to advance the existence of a perfect QECC. Following Verlinde and Verlinde [9] we posit the existence of an operator which transfers entanglement between a black hole and Hawking radiation into an entanglement with an ancillary set of states and the radiation. This operator projects out states not within the code space, which means the operator is not purely unitary. We may then propose an operator $\mathbf{R}$ that acts on the ancillary states as $P \ = \ {}_a\langle 0|\mathbf{R}^\dagger\mathbf{R}|0\rangle$, where for $\mathbf{R} \ = \ \sum_n R_n \ = \ \sum_{n,i} e^{E_n\beta/2}C_n|i\rangle$ gives the projector

$$P \ = \ \sum_n R_n^\dagger R_n \ = \ \sum_{i,n} e^{E_n\beta}C_n|i\rangle\langle C_n^\dagger. \tag{3.11}$$

It is easy to see that $P^2 \ = \ P + error$.

This operator is able to project states that are within the coding space. This space could be extraordinarily large, such as a Steiner system for the Leech lattice. The projector on the unitarily evolves states is in general $PU|i\rangle|0\rangle \ = U|i\rangle|0\rangle$ + error. The left hand side is easily seen to be

$$PU|i\rangle|0\rangle \ = \ \sum_{j,m,n} e^{E_n\beta}C_n|j\rangle\langle j|C_n^\dagger C_m|i\rangle|m\rangle \tag{3.12}$$

In the case the code size $N_{code} \ << \ N_n$ the overlap or interference term is given by $C_n^\dagger C_m$ and peaks at $m \ = \ n$. However, the $C_n^\dagger$ and C_n also interfer and this results in the growth of N_n states and an error operator $E \ = \ \sum_n(N_{code}/N_n)\mathbb{I}_{M \ - \ E_n}$, where M is the black hole mass.

The difficulty that exists is this error correction code is set to shift entanglements between the black hole and Hawking radiation to the ancillary states and Hawking radiation so that the Bekenstein bound is not exceeded. If the error operation were zero it would mean that in effect there is a computer that computes radiation states and a computer that matches these to a set of coding states. The pure error correction would mean that the two systems act perfectly. Further we have a situation where one computer is set to determine when the other computer makes a wrong computation. However, this is a paradoxical situation, which makes such perfect error prediction impossible. We may see this with the case of an MH machine, call this MH, that makes the correct hypercomputation, and the black hole and QECC computers B and Q that compute states. We expect that Q is able to correct the output of B. We then have the output of MH intelligible by B. It is then not possible to have Q output a bit that is the correct response to the output of B.

In order for the physics to hold there must then be a hypertasking system that performs the correction. This correction means there must be some process by which the unwanted states in N_{code} as it approaches N_n are reshuffled in some manner. This means these states are removed from the universe, such as by generating a nascent cosmology, or they have some physical manifestation on the event horizon. This could mean there is a form of hair on the even horizon, or there is some generalization of nonlocality. These may in the end be forms of the same thing. The addition of hair, via stringballs, is Mathurs solution to the firewall problem [10]. There may be a new form of nonlocality which permits an uncertainty between entanglement types. The hair on the event horizon may then be a type of quantum gravity noise associated with this nonlocality, which also breaks up the entanglements between the black hole and Hawking radiation. This may in turn have an internal interpretation as the quantum formation of a nascent cosmology from the interior of a black hole.

The QECC recovery operator connects the interior states with ancillary states in the Hilbert space $\mathcal{H}_a$ to the system state in $\mathcal{H}_A \otimes \mathcal{H}_a$. This operator $R_n = e^{-E_n\beta}\sum_i |i\rangle\langle i|C_n^\dagger$ into the super-operator with the ancillary states with the composition

$$\mathcal{R}|j\rangle|0\rangle_a = \sum_n R_n|j\rangle|n\rangle_a. \tag{3.13}$$

The super-recovery operator is unitary if the QECC is perfect. The super-operator defines a projector $\mathbb{P} = \mathcal{R}^\dagger\mathcal{R} = \mathcal{R}\mathcal{R}^\dagger$, which gives unitarity if the projector is a unit matrix over the whole $\mathcal{H}_A \otimes \mathcal{H}_a$. This obtains if $\sum_n R_n^\dagger R_n$ is a projector. This holds for the ideal QECC operator. The propagator is connected to the QECC superoperator $\mathbf{R}$ that associates the observable O into the interior black hole Hilbert space

$$\mathbf{O} = {}_a\langle 0|\mathbf{R}^\dagger O\mathbf{R}|0\rangle_a, \tag{3.14}$$

for the vacuum state in $\mathcal{H}_a$, the ancillary Hilbert state space. The square of this operator is evaluated $\mathbf{O}^2 = {}_a\langle 0|\mathbf{R}^\dagger O\mathbf{R}\mathbf{R}^\dagger O\mathbf{R}|0\rangle_a$, with the unitary condition $\mathbf{R}\mathbf{R}^\dagger = 1$, or approximation as an idempotent operator or projector on $\mathcal{H}_A \otimes \mathcal{H}_a$.

The breakdown in the QECC, or the departure from unitary is a measure of the loss of locality. This breakdown in locality means there is a greater uncertainty in the entanglement structure of quantum states. A bipartite and tripartite entanglement may exist as superpositions with some uncertainty as to which obtains. It is the case then that the evaluation of the propagator is equivalent to the evaluation of energy or moment with the reciprocal position as the outcome. The above Greens function is then a measure of the loss of locality or entanglement established by local physics so that

$$I \simeq \frac{\left(\langle 0|\mathbf{R}^\dagger O(x)\mathbf{R}\mathbf{R}^\dagger O(y)\mathbf{R}|0\rangle_a - \langle 0|\mathbf{R}^\dagger O(x)\mathbf{R}|0\rangle\langle 0|\mathbf{R}^\dagger O(y)\mathbf{R}|0\rangle_a\right)^2}{2|O(x)|^2|O(y)|^2}. \tag{3.15}$$

has a harmonic condition with the Greens function. The breakdown of locality means that units of information not corrected by QECC are discarded. These uncorrected qubits of information are then jettisoned from a blackhole into a nascent cosmology.

The effective action of equation 17 is equivalent to the mutual information in equation 2. Entropy and action are in a euclideanized format equivalent with a Euclidean time $\tau = it$ such that $\tau = \hbar/kT$. The action defines the Lapacian which operates on the propagator so that $(\Delta + m)G(x,\, y) = 4\pi\delta(x - y)$ The propagator of system is then the kernel of the operator that is evaluated by the operator or equivalently the mutual information. This quantum information in the BH interior is then allocated to a nascent cosmology with $I^* \simeq e^{-|x\, -\, y|}$.

In an open multiverse quantum information or qubits are conserved locally. No observer is able to observe the creation of a quantum bit, or the duplication of a quantum bit or EPR pair. However, globally this conservation does not obtain. Quantum bits that accumulate in the ancillary quantum state space of a QECC are associated with different spacetimes that occur upon an orbit around the singularity. This is a form of branch cut which assigns a new Riemann sheet to every orbit, where quantum bits generators or created are assigned to each sheet.

The process is a type of hypercomputation, which no local observer can ever read an output from. The local conservation of qubits is then equivalent to the Church-Turing thesis that computable functions are recursive functions in the sense of the λ-calculus that are executed on a Turing machine. In the hypercomputation over a larger region of P-space, a class of supertasks exist in a more global setting. In local physics the execution of a supertask cant be observed by an observer in a timelike region I. An observer in the interior of the BH can measure such outcomes near the r_- Cauchy horizon. The output of this infinite computation requires the deposition of information on new Riemann sheets. The observer capable of witnessing the hypercomputation is then able to witness the duplication of qubits and the generation of qubits from nothing.

The exterior observer however may not be completely blind to this. The event horizon is subject to quantum fluctuations which make the interior configuration of states superposed with states on the exterior. The exterior observer may then be able to observe a form of oracle output from the interior hypercomputation. The superposition of exterior states with interior states means it will not be possible to observe duplicated states in the interior. However, this will mean that quantum states in the exterior region will not be statistically independent as with standard Hawking radiation. Quantum states will be in coherent states analogous to laser states of light. Quantum black holes will then exhibit a departure from black body boson statistics with a different phase similar to lasers states of light.

4 The local and global landscape

Having built up this idea of hypercomputation, it is now taken down several notches. The parameterized Schwinger action illustrates there exists a certain cut-off in scale. The path integral for $t = \tau/\sigma$ is such that for $t \rightarrow 1$ the time and space parameters interchange. There is no real physics beneath a certain scale. This means the pile up of signals near the r_- inner horizon may become blurred near the horizon and no receiver can parse the message. We also have the fact that a black hole is not eternal. Black holes quantum mechanically radiate bosons, and in a universe that is exponentially expanding away there will eventually be no external mass-energy to supply the black hole as it loses mass. The duration of a black hole is finite, even if that is a tremendous time scale of up to 10^{110} years. So the actual infinitude of this process may be a sort of fiction. We then have to ponder what a finite form of this hyper-Turing machine would be.

For the Kerr black hole the inner horizon is a region where geodesics from the outside are blushifted and accumulate at a single point in the spacetime. This is what defines an MH spacetime that computes supertasks. Holographic states on the inner horizon are dual to states entering from infinity. These states can process in a finite period of time the vast quantum bits in the exterior universe. In this way the landscape is computed.

The singularity is a Planck wall of information. The smallest region a qubit of information can be contained in is a Planck unit of horizon area. We know that $e^s = dim(\mathcal{H})$. If we think of the entropy per k $s = S/k$ as the Euclideanized from of a path integral, eg $1/kT\ \tau/\hbar$, then if $\tau = it$, then we are burying away the quantum phase or action, or action per unit $\hbar$, into a real valued quantity. We have then the correspondence

$$entropy\ per\ k \leftrightarrow action\ per\ \hbar.$$

This corresponds with the treatment of Euclideanized time as the reciprocal of temperature. The action per $\hbar$ is of course the number of states occupied by a system $N = dim(\mathcal{H})$, really the dimension of the Hilbert space occupied, and so we have $s = ln(dim(\mathcal{H}))$, which is a quantum form of Boltzmanns famous equation $S \ = \ k \ log\Omega$. For the qubit system in bipartite entanglement with the black hole the number of possible horizon units for entanglement is 2^n. The space problem in computing the configuration of a black hole is then NP-complete.

The compactification of a Calabi Yau (CY) manifold X of the type IIB on the $D3$-brane is given by $L/(2n+3)$ where n = the number of complex moduli[14]. The topological index

$$L \ = \ N_{D3} \ + \ ?F^{RR} \wedge F^{NS}, \tag{4.1}$$

such that the $D3$-brane charge N_{D3} adds to the Euler index $L \ = \ N_{D3} \ + \ \chi(X)/24$. The 24 comes about becomes of Dedekind functions of modular forms. I have written about these before. The expectation $\langle R(D3)\rangle_\Lambda \ = \ L/2(n+1)$ evaluates $D3$-charge or flux as the cosmological constant. We have the standard model group G_{SM} that exhibits configurations or a flux on the $D3$-brane that has a large number of possible outcomes $G \ \sim \ G_{SM} \times \mathbb{C}$, where $\mathbb{C}$ is the complex plane of possible configurations. The measure of the number of configurations which can hold the standard model is then

$$\nu \ \simeq \ exp\left(\frac{R_{SM}}{\langle R(D3)\rangle})\right) \tag{4.2}$$

This measure, particularly with the above four-form $F^{RR} \wedge F^{NS}$, on the $D3$-brane, is dual to the intersection form of the gauge field on the four-manifold. This is a measure of the quotient space construction of the moduli = AdS_5. This also is related to the projective orbit space of entanglements. These entanglement space-groups describe the entanglements of qubits with the black hole.

In this way the landscape is computed. The computation is NP-complete, and a discrete form of the MH-spacetime means that NP-complete problems are computed in P space or time. Black holes are then the quantum Turing machines that calculate the landscape.

The simplest CY manifold is the T^6, though $K3$ permits Plucker coordinate system of $S^2 \times S^2 \# E8$ and is more physical, and we can reduce this to T^2, or $T^1 \ = \ S^1$. The occurrence of these CY at every point in the Minkowski spacetime is dual to an enlarged CY with a Minkowski spacetime at each point. In the case of just S^1, a unit circle in the $\mathbb{C}$ above in the description of the flux on the $D3$-brane $G \ \sim \ G_{SM} \times \mathbb{C}$. Each point on the circle contains a spacetime similar to ours based on the same initial conditions of our universe. If we extend to $T^2 \ \sim \ S^2 \ - \ 2(pt)$ this additional direction involves cosmologies with similar initial conditions. Other topological direction begin to involve other brane wrapping topologies for fluxes.

5 Conclusion

This really should not be called a conclusion. The one thing the hyperTuring machine example here does suggest is that there must be some form of new physics. This clearly illustrates how black hole quantum mechanics, or quantum gravity in general, must involve some new type of physics. The hyperTuring machine is a system that produces a new postulate or axiom, which when employed the physics system is able to perform the operation correctly. In this case the operation is to prevent the runaway entanglement of Hawking radiation and black hole states.

The direct operation of this sort of system has the effect to rapidly speeding up the NP-complete problem of computing the landscape. How this happens is still not explicitly clear. If nascient cosmologies are generated in black hole interiors the computation may then be to compute or select the element in the landscape for that universe.

The existence of an actual hyperTuring machine in the universe, whether in a black hole or with the universe in its entirety, is problematic. The difficulty is that this tends to imply an infinite computational space. Black holes exist for at most around 10^{110} years. A neutron star can exist for a very long period of time. Using a quantum estimate for the neutron star with self energy GM^2/r can tunnel through the barrier into becoming a black hole with $k \quad \sqrt{2M}/\hbar\sqrt{\delta V} \ \simeq \ 2 \times 10^{81}$ The probability for tunneling into a black hole across a distance of $\simeq \ 10^3 m$ is then $P \ \simeq \ e^{-10^{84}}$. This translates into a time duration of about $10^3 m/c \times (1/P)$, and this is about $e^{10^{66}}$ seconds. This is not terribly different from the estimate Freeman Dyson quoted [15] of $10^{10^{76}}$ years for all matter to decay into black holes. For neutron stars this estimate may be somewhat higher. So while these objects may exist for enormously long periods of time they are not eternal. This means that black holes will not exist eternally into the future. This precludes some sort of hyperTuring machine as due to an ensemble of black holes far into the future.

This does not mean however that the hyperTuring machine as the ideal second order λ-computing system is worthless. In the field of the S-matrix, which is the progenitor of string theory, there was an idea of shadow states[16]. These are states which do not correspond to a probability, but which still have a dynamic role. The optical theorem for the scattering and transition matrices result in a Greens function, such as in equation 18. This formalism may be used to describe shadow states with

$$G = (E - V + i\epsilon)^{-1} \rightarrow (E - V + i(1 - \sigma)\epsilon)^{-1} \tag{5.1}$$

for σ a form of projector. This projector operator may perform the role of hypercomputation by projecting onto states computed by the second order λ-calculus. These states however play no role in probability, and by the Born rule play no role in any direct observable.

The reason this should not be really called a conclusion is that this suggests more of a beginning. Using hypercomputation might be a way of looking at the phase structure of spacetime. This is even if there are no physically observable quantities associated with them. In addition this may have some bearing on the computation on the landscape. This is then more likely the start for various avenues of investigation than a conclusion.

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