Emergent Holographic Newtonian Gravity

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1 Introduction to Verlinde's Emergence.

Quantum gravity could arguably be considered the most important unsolved problem, often considered the Holy Grail of physics. Emergent gravity has been among the more promising directions for resolving this theory, and bringing gravitation into the quantum regime. I have just made considerable progress in bypassing the renormalization of the quantum partition function in the ultra violet, by making a significant contribution to emergent gravity.

While string theory and loop quantum gravity remain common approaches, emergence incorporates elements from these other theories, while essentially remaining thermodynamic and information theoretic at its core. Much of the work of Bekensetein, Hawking, and Unruh are utilized to explain gravitation, this utilizes the relevant concepts from black holes, including event horizon surface area entropy as well as Hawking radiation. We see that not only do accelerated frames radiate, we also hypothesize that this heat is driving gravitation.

The preliminary 2010 emergence article, which was vetted and approved for publication in 2011 in the Journal of High Energy Physics, has been cited almost fourteen hundred times at the time I am writing this. Most of this article is dedicated to reviewing Verlinde (2011). On the Origin of Gravity and the Laws of Newton by Erik Verlinde, and in doing so, I made a number of original contributions to emergent gravity, especially in the last few sections.

Thermodynamics is a microscopic theory of a macroscopic system. Emergence is a quantum theory of gravity. Further, I intend to make the mechanism for which the entropic force is being manifested (via entanglements). It is merely that the emergent phenomenon can only be explained as being the result of the sum of its parts but not explained by the individual microstates. It is the entropy of these microstates that is driving the emergent force. Further examination, and claimed by Verlinde, we see that space itself is emergent. In a holographic sense, even the notion of force is emergent. Hence we arrive at Newtonian concepts, that are derived from the thermodynamics. Gravitation is explained in terms of spreading entropy.

What is at stake here, is one of the leading approaches to solving the quantum gravity problem, and is not a trivial matter. If this both elucidates the theory as well as points out and fixes a hole in the theory, this is of high importance. So far, many details of this theory have not been made explicit, including the bits themselves (what are they).

This article begins by reviewing concepts from thermodynamics in §2.1, and making clear in which senses I am using those concepts. For the readers unfamiliar with polymers, I also reviewed a standard textbook mode within §2. The polymer is used as an analogy for entropic forces. I then elaborated on the Holographic Priniciple and how it is used to explain Verlinde's theory of emergence[1]. Other pre-requisite topics are discussed at length, such as Compton frequencies, Planck scale units, black holes, and qubits.

Once the foundation is set, I then go on in §3 to explain Verlinde's theory of emergence itself, in the Newtonian approximation. The vaguest picture without doing it justice, is that gravitation is powered by thermodynamics. An appeal to polymers can be made, however I endeavored to build the model in a manor that is free from polymers, as concerns are raised in §4. We use vector forces instead of the scalar approach used in the orginal model. I briefly examine partition functions.

I then go on in §4.2 to review a number of concerns raised by Saun Gao in 2010 regarding the validity of the polymer analogy as well as concerns regarding causality. I believe I have argued succesfully that emergence can be rescued once these concerns are addressed. I have rectified the concerns of causality within thermodynamics itself, even independently of entropic

[1]The holographic Principle comes from string theory, however we will not depend on string theory in its entirety for this theory to work. If anything, there are certain things that we can salvage from string theory.

gravity. I have provided a summary of what can be claimed from the model even if gravity is not a polymer, but some other entropic force at the end of that section.

I found a significant flaw in the 2011 version of emergence, which appears to have not yet been commented on, whereby the system is leaking entropy. I intend to explain how this can be repaired by increasing the energy subsystems to also include the energy leaking out (I propose that the heat is working to expand the volume of emerged space, and the heat is naturally flowing into the next closed surfaces out, concentrically, so that the entropy of the universe still goes up, even if the entropy of one closed surface goes down in certain cases). It simply means that what was thought to be a closed system was not quite closed yet.

How does the heat flow perform work on the particle, other than that there seems to be an entropic force at work? Many important questions can be answered here.

In §5, that has the most original material, I checked reversals, of which concerns regarding time reversal are mentioned often when discussing this subject. Within displacement reveral, I found some energy leaking out of the model, which has never been commented on before. I explain how this leads to an experimentally testable prediction for emergent gravity. Once the energy leak is fixed, the amended model predicts an an-isotropic cosmic expansion. An experimental correction to the Einstein equation would be considered strong evidence of the validity of emergent gravity. What my theory predicts is that the dark energy in the universe is not uniformly distributed. Einstein gravitation could eventually be considered an approximation of a stronger model of emergent gravity.

2 Entropic Forces and the Holographic Principle.

2.1 1st Law Thermodynamics.

The 1st law in the energy representation tracks the flow of energy into and out of a thermodynamic system. E is the energy, S is the entropy, V the volume, N is the number of elements in the system, X is distance.. $T = \left(\frac{\partial E}{\partial S}\right)_{X,V,N}$ the temperature, $P = -\left(\frac{\partial E}{\partial V}\right)_{S,X,N}$ the pressure. Pressure is units of force per area, and the force is acting on an area, expanding the volume of the container. When multiplied, pressure times volume gives units of work energy. $\mu = \left(\frac{\partial E}{\partial N}\right)_{S,X,V}$ the particle pressure (or chemical potential),

Force acting over a line is also mechanical work, which changes the energy of the system (E). The variable X tracks the distance over which the force acts, $F = -\left(\frac{\partial E}{\partial X}\right)_{S,V,N}$.

With all of these types of energy within the system changing, the total change of energy in the system can be computed:

$$\begin{aligned} dE &= TdS - FdX - PdV + \mu dN \\ &= \left(\frac{\partial E}{\partial S}\right)_{X,V,N} dS + \left(\frac{\partial E}{\partial X}\right)_{S,V,N} dX + \left(\frac{\partial E}{\partial V}\right)_{S,X,N} dV + \left(\frac{\partial E}{\partial N}\right)_{S,X,V} dN \end{aligned} \tag{1}$$

If you write a fundamental equation $E(S, V, N)$ in the energy representation, then energy will tend to reach equilibrium at its minimum.

At the moment, this is a mathematical model, and no example is given yet. You should already have some intuition about these concepts from thermodynamics.

Different kinds of energy can be converted into one another, here we are tracking the flow of heat Q in the form of changing entropy S, which can be converted into (mechanical or particle) work W (or vice versa). This is such that $dE = \delta Q + \delta W$, how the two types of energies change are path-dependent, change is denoted δ, the total energy that enters or leaves the system is path-independent, so it is denoted dE. In this model, the differentials d and δ can be thought of as infinitesimal in the sense of a continuum. I will explain when this changes to discrete steps at which point I will use Δ to denote a finite change, as more than an infinitesimal change.

When no particles are being exchanged, and the volume is not expanding, the first law in Energy representation is $dE = \delta Q + \delta W = TdS - FdX$. This is, for example a rubber band pulling on an attached mass.

The temperature $T = \frac{\partial E}{\partial S}$ is the conversion factor between heat energy and entropy/information. It is important to note the sense in which I am using temperature througout this article. This is the amount of energy that can be available for work produced by the changing of the entropy bits of information (however, we are still working in thermodynamic units using k_B), which occurs spontaneously.

Within the conversion of heat energy δQ into mechanical work energy δW, the forces acting are defined as "entropic". The pressure $P = -\left(\frac{\partial E}{\partial V}\right)$ is the amount of work energy per unit of volume change. The force $F = -\left(\frac{\partial E}{\partial X}\right)$ is the amount of work energy change per unit of distance over which that force acts.

The sense in which I am using the term "information" in this article, is definitionally, the changing of entropy. If entropy decreases, then the information increases. When entropy increases, information about the system is lost. Information is used almost interchangably with entropy, except when in motion they are exactly converse to eachother.

2.2 2nd Law of Thermodynamics.

In the case were the entropy does not change, and if $\Delta S = 0$, then a process is regarded as *reversible*. If the energy of a system does not change, i.e. $\Delta E = 0$, then an energy system is regarded as *closed*. Only in the case of a closed system, the total entropy tends to increase, or stay the same, i.e. $\Delta S \geq 0$. This is to say that if a force is *entropic*, it could be thought of as being powered by the statistical tendancy of the total entropy of the closed system to increase.

If you have a fundamental equation for entropy in $S(E, V, N)$, then it will tend to seek it's maximum when reaching equilibrium. I will often suppose the existance of some entropy S in that it exists, and I will utilize that it exists theoretically, often without writing out the fundamental equation explicitly. The principle of the thermodynamic system seeking to maximize its entropy, when reaching equilibrium, is essential to a thermodynamic picture of forces.

2.3 Polymer/Rubber Band.

Callen[2] is my source for the thermodynamic polymer. As a simplistic model, the links of the individual monymers are oriented either in the x-direction,

[2]Callen's Thermodynamics §15.4.

or in the y-direction. For example, a link that leans towards the positive x direction will contribute one unit to N_x^+, in the negative x direction a link contrbutes one unit to N_x^-. Links that fall along the x direction do not directly contribute to the total energy of the polymer U. A link in the positive y direction adds one number to N_y^+, and similarly a link that falls in the negative y direction adds one number to N_y^-. Links that are oriented either in the positive or negative directions of y contribute one increment ε of energy to the U. The total number of monomer links in the chain is $N = N_x^+ + N_x^- + N_y^+ + N_y^-$. The rational for the vertical links to contribute energy is that they will "interfere", or bump into other polymer chains in a bundle.

The model implies that the energy is $U = \varepsilon(N_y^+ + N_y^-)$, and the x and y direction lengths are $L_x = a(N_x^+ - N_x^-)$ and $L_y = a(N_y^+ - N_y^-)$, where a is the length of one monomer.

The rubber band is placed in a reservoir of heat. The polymer is allowed to exchange entropy with the reservoir (also called a "heat bath"). A mass is attached to the rubber band, and as the polymers seek entropically favourable configurations within the heat bath, the writhing of the rubber does work on the mass.

For this system, the monomer links form a microcanonical ensemble, and one can count the number of microstates for a given configuration using a multinomial coefficient: $\Omega = \binom{N}{N_x^+, N_x^-, N_y^+, N_y^-} = \frac{N!}{N_x^+! N_x^-! N_y^+! N_y^-!}$. It is then straight-forward to write this in terms of the variables $\Omega = \Omega(U, L_x, L_y, N)$, as well as compute the entropy of the rubber band itself, $S = k_B \ln \Omega$ (or more generally, this can be used for a micro-canonical ensemble where the microstates are ergodic). When the polymer is placed in a heat bath, the entropy will tend to want to increase, and resist any force parallel to the line and stretching the rubber band back out.

As is often the case when a force applied in one direction (along an axis), such as a polymer, the mechanical work is $\delta W = -F dx$. This is similar to the force being spread out over a surface area in the form of pressure, except in this case the force is applied along a line. If the force is understood to be related to changing entropy in this way, it can be regarded as entropic. One sees that in the case of the polymer/rubber band, the statistical tendancy of the total entropy of the universe to increase, is what seems to compel the rubber band to pull a mass inwards and reach an equilibrium with the mass that is stretching it out. In the polymer model, $F = -\left(\frac{\partial U}{\partial L_x}\right)_{S,N}$. Notice that there is indeed a force in the x direction. In the case of a usual rubber band, the energy is allowed to flow into and out of the rubber band as it exchanges energy with the heat bath. If this is the case, the system is regarded as *open* in regards to energy. I will distinguish cases where I will use E to represent the energy, or U to represent the internal energy of a particular system, in this case, U is representing the energy within the polymer itself.

It is also common to regard the 1st law in the entropy representation as equivalent to the 1st law in energy representation(1) (setting $dN = 0$):

$$dS = \left(\frac{\partial S}{\partial E}\right) dE + \left(\frac{\partial S}{\partial x}\right) dx = \frac{1}{T}dE + \frac{F}{T}dx$$

What is important to note regarding the 2nd law §2.2 here is that the usual polymer uses an open system, where energies are exchanged with the heat bath, and $\Delta U \neq 0$. In this case, the entropy of the rubber band is expected to rise and fall accordingly. When the rubber band becomes more coiled, it seeks additional possible microstate configurations, and its entropy goes up, when it gets stretched out in the x direction, the number of potential microstates goes down, and so does its entropy (this is assuming a constant temperature T). One imagines heat flowing into and out of the rubber band, with the heat bath, when the entropy of the rubber band changes.

2.4 Compton Frequencies.

For a given particle of rest mass m, the Compton wavelength is an optical quantity, $\ell_C(m) := \frac{h}{mc}$. This is the wavelength of light at the same frequency/energy as the rest mass of the particle: $mc^2 = \delta E_m = \frac{hc}{\ell_C(m)}$. It is difficult to isolate particles within distances below the length scale ℓ_C. The light that you use to measure position affects the position you are measuring, by imparting the light's energy to the particle. Prior to observing the position of the particle, within uncertainty, the particle is in a wave function ψ. A particle does not have an explicit position, within uncertainty, until the position is observed. ℓ_C is also a statement about uncertainty of measurement of the position observable $\hat{X}$. It takes so much energy to observe particles below this distance length scales that it can actually cascade and create new particles reference desired. For an electron, $\ell_C(m_e) \sim$ pico-meters.

2.5 Unruh Radiation.

[Verlinde] (3.4) is: $2\pi c k_B T = \hbar \left| \frac{d^2\vec{x}}{dt^2} \right|$. This sets up the proportionality of temperature to accelerated frames. Of which Newtonian force is a derived concept. The entire theory is predicated on the possibility that this heat of the vacuum is powering gravitation itself.

Consider the general massless covariant wave equation[3]:

$$\frac{1}{\sqrt{-\det[g]}}\partial_\mu \left(\sqrt{-\det[g]}g^{\mu\nu}\partial_\nu\psi\right) = 0$$

Here g is the metric tensor. This can be contrasted with the familiar form of the wave equation $\partial_t^2\psi = c^2\nabla^2\psi$. It is not difficult to see that this is the wave equation in flat Minkowski space, such that in geometerized time units, it is equivalent to $\partial_\mu\eta^{\mu\nu}\partial_\nu\psi = 0$. The general wave equation is further motivated by the fact that $\det[\eta] = -1$. It would be preferable to show explicitly why the $\sqrt{-\det g}$ is differentiated (which I skipped due to expediency). It has something to do with the fact that the metric tensor could be changing everywhere. In reality, the metric tensor is multi-linear up to the length scale of the mesh-size (hoping to use Planck units), I digress here.

Now, the metric will depend on the question being asked, and the length scales discussed, along with any approximations that are made. It is here that we discuss the creation of particles as the result of horizons in the quantum field. By comparing Schwartchild and Rindler metrics, we see that there is a temperature in the field as the result of the offset of creation and annihilation operators on frequencies that would otherwise be balanced in a flat vacuum. There is a direct similarity between event-horizons and Rindler horizons that lead to the creation of particles.

general state solutions and corresponding isomorphism to frequency space

[3] Which is equation (4) of Davies, P. C. W. (1975). "Scalar production in Schwarzschild and Rindler metrics". Journal of Physics A. 8 (4): 609âĂŞ616.

and summed over nodes are such that[4]:

$$\hat{\phi}(\vec{x},t) = \sum_{\vec{k}} f(\vec{k},t)\hat{a}_{\vec{k}} + f^*(\vec{k},t)\hat{a}^\dagger_{\vec{k}}$$

The creation operator is $\hat{a}^\dagger$, while the annihilation operator is $\hat{a}$. (In flat Minkowsi space these solutions are precisely the traveling waves $f_{\vec{k}}(t) = \exp i(\vec{k}\cdot\vec{x} - \omega_{\vec{k}}t))$. The vacuum state is the particular solution to the wave equation such that when anihilated it yields zero: $\forall \vec{k} : \hat{a}_{\vec{k}} |0\rangle = 0$. In my mind, this is basically saying that the vacuum state does not have any particles at those locations because there are no particles with which to annihilate by $\hat{a}$[5].

Then, a horizon separates space in that particle trajectories get redirected when inside the horizon, whereas outside the horizon, particles can escape. This creates an offset in the creation/anihilation solution of the previous vacuum state. Particle/anti-particle pairs are created and thus entangled with eachother; one particle on each side of the causally seperated regions. In the case of black holes, one particle inside the black hole, and the other outside the black hole. (See p.16 [Ohio]). This leads to Hawking radiation.

The argument for the creation of particles is extended to include the appearance of horizons in accelerated frames, for this I looked at [Davies]. We define Rindler coordinates as $z^2 := \vec{x}^2 - t^2 = \ddot{\vec{x}}^{-2}$ and $v := \mathrm{arctanh} t/|\vec{x}|$ (It would be nice to show that $z = |\ddot{\vec{x}}|$). Here $(\vec{x},t)$ are the Minkowski coordinates.

In this case the particular solutions of the wave equation are [Davies] (7):

$$f_\omega \sim \omega^{-1/2} \exp i\omega(v + \ln z)$$

The existence of particles generated by causal horizons are actually observer dependent, with particles being generated in the accelerated frame. Otherwise, to an inertial observer the heat would be measured as friction due to space reference or proof desired.

In this context, all accelerating frames radiate, and all forms of energy gravitate.

A black hole event horizon is the location of a holographic screen of Verlinde's theory, as an example.

[4]Quantum Field Theory Lecture Notes Ohio State equation (1.48)

[5]There are some issues with this discussed on p.12 of the Ohio State lecture notes).

2.6 Holographic Principle.

In Gauss's Law, the information about the electric charges within the bulk of arbitrary closed surfaces are stored in the $\vec{E}$ field on the surfaces themselves. The bulk volume is denoted V, the closed surface[6] as the boundary to the volume is ∂V.

Similarly, we have Gauss's law for gravity: $\oint_{\partial V} \vec{g} \cdot d\vec{A} = -4\pi GM$. Here you can see that all of the information about the mass M that is enclosed is stored on ∂V and tracked by the gravitational field $\vec{g}$. For this article, G is the Newtonian gravitational constant.

The Unruh temperature T is the temperature of space, and is proportional to the acceleration a. Acceleration a is what the hypothetical Newtonian field would experience, which is also tracked as a potential energy. The temperature is how the holographic principle comes into play with the gravitational model. This is made explicit in the equipartition[7] of [Verlinde] (3.7) $E = \frac{1}{2} N k_B T$. The energy of the matter is spread out onto the N bits on the surface of ∂V. This is how the information regarding the enclosed matter, that is stored on the surface, is manifested as an entropic force. One can think of $k_B T$ as a rate of how much energy can be extracted per bit of information.

In Gauss's law, the surfaces are arbitrary. Verlinde tends to use equipotential surfaces (for the purposes of thermal equilibrium) [8]. In the most simplest model of uniform matter density gravitation, as is customary with the approximation for spherical worlds (and Newtonian gravity), the closed surfaces are spheres and the temperature on the surface is in thermal equilibrium, and at the same temperature throughout.

The information is equipartitioned onto surface area bits[9]. Entropy can be measured in units of bits, although equivallently, throughout this article I

[6] In the Verlinde article, the closed surfaces are called "holographic screens".

[7] I have had some questions regarding the equipartition itself which goes beyond the scope of this paper. It seems that the energy would spread out into the microstates themselves as opposed to the bits as a measure of entropy. However, on the other hand, at best this would involve a conversion factor of $\log_2 e$ to put the energy into the correct units of ST, where S is the thermodynamic entropy. The $1/2$ comes from the fact that the bits are in binary. In this sense of simply being energy per bit, this works just fine.

[8] Concerns were raised recently in Wang and Braunstein (2018)*Surfaces away from horizons are not thermodynamic* Nature Communications.

[9] Other than bits being in surface area units of planck areas, the bits themselves are not made explicit in the literature, which I would like to follow up with in future articles.

will usually be using thermodynamic units (k_B and logarithm base e)[10]. The theory of emergence is that the temperature and entropy on the surfaces are powering gravitation. This is holographic in the sense that the information on the closed surfaces are generating the field[11].

2.6.1 Dimensional Reduction.

We salvage and make heavy use of the holographic principle from string theory; that there exists a dimensional reduction [12]. We make use of existence of the (3+1) dimensional reduction onto (2+1) dimensional holographic screens (instead of event horizons)[13]. In the first Newtonian approximation, these are spherically symmetric surfaces[14]. The dimensional reduction equation does not need to be known for the thermodynamic model to be analyzed in terms of changing entropy, and thus mechanical work on particles undergoing gravitation, tracked via the 1st Law exchange of energies. The dimensional reduction must exist for this to work, it does not need to be known yet. The dimensional reduction is never made explicit anywhere, as far as I can tell. The dimensional reduction onto 2D is used in the sense that it "exists", but the actual equation has never been derived.

I outline my program for deriving such an equation in §6.1. This will involve writing a quantum computing algorithm for holographic storage of particle frequencies.

2.6.2 Planck Area Pixels

Another ontological claim regarding fundamental reality, which is underpinning the emergent gravity theory is that the 2D surfaces are quantized in such a way as to have discrete units of Planck lengths[15]. These are length units $\ell_P = \sqrt{\frac{\hbar G}{c^3}}$ that are regarded by some as the theoretical minimum

[10] $N = \log_2 \Omega$ and $S = k_b \ln \Omega$ are both measures of the same entropy, where Ω are the microstates

[11] Other Newtonian concepts are also generated via the Holographic Principle within the Verlinde article.

[12] This is related to Carlip's work

[13] In the future, I hope to make this dimensional reduction by writing out an explicit algorithm, which has not been done before.

[14] Verlinde later extends this to equipotential screens, I can explain that this raises some concerns later in the paper.

[15] Do the Planck scale area units undergo Lorentz contractions?

length that is fundamentally possible. Recall that for particles distances were quantized at the minimum length scales of ℓ_C.

What this means is that the hologram is quantized around the particle that is being projected (is emerged via ℓ_C), as well as the amount of energy contained within the sphere V (but is not emerged via ℓ_P), as a discrete grid. This can be thought of as the qubits forming the discrete lattice of solid state physics, only here we are at the Planck scale, not the scale of mesophysics.

For entropy bits of information on the surfaces ∂V, for each Planck area unit, ℓ_P^2, one pixel can hold exactly one bit of information. When in superposition, this can work out to one bit of entropy. If one entropy bit collapses to a bit of information, then Landauer erasure heat is released and the emerged particle further entangles with the qubits of the screen by acting as an observer of the qubits. Similarly, the particle is being observed by the screen, and information is being exchanged between them.

The surface area of the holographic screen generally is $A = \oint_{\partial V} \hat{n} \cdot d\vec{A}$. In the case of the spherically symmetric screens that we are using for this article the surface area is $A = 4\pi R^2$, where R is the radius of V. Since the surfaces hold one bit of data per unit Planck surface area, the number of bits is $N = \frac{Ac^3}{G\hbar}$ [Verlinde] (3.6).

2.7 Holographic Screen Digital Entropy.

Everything relies on the N bits of entropy on the holographic screen surface area, and how they cause gravity and space itself to emerge. And yet where are the meaning of the N bits made explicit? There is this notion that the space is emerged from the bits, and they seem to be in binary. Coordinates in all of the articles I have read are left vague. There is a dimensional reduction at play, and it is regarded as important in the literature, and I have not found the dimensional reduction written out explicitly anywhere.

The bits must be qubits for this to work.

If the dimensions are not emerged, then they exist as entropy and energy on the screen. If the dimensions are emerged, then the coordinates should be stored holographically on the qubits. The bits can store coherent and interfering frequencies of particles, whereby some of the bits are entangled with the emerged particle. One imagines the particle that is emerged from the screen as an energy hologram from frequency bins on the screen. This is more than an analogy. The screen qubits supply entanglement pressure.

This makes the quantum gravity physically manifested via an entropic force.

The holographic screen has a finite number of pixels which have entropy, measured in bits (or in thermodynamic units). As the entropy on the screen increases, this does work on the emerged particle, pulling it towards the screen, even absorbing it. Each pixel has energy, which when is equal to the amount of mass energy that would be on the interior, if it were emerged. I believe that I can explain this physical mechanism (of gravity) in terms of entanglement pressure, claiming that the particle is entangled with the qubits on the screen in a holographic way.

If a single qubit quantum state is $\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$, and we make the assumption that each Planck cell of area on the screen holds one qubit of entropy. If we combine the quantum states into an overall state vector on the area of the screen we have:

$$|\psi\rangle = \bigotimes_{i=1}^{N} 2^{-N/2}(|0\rangle + |1\rangle) \tag{2}$$

$|\psi\rangle$ has 2^N potential microstates, hence N bits of entropy[16].

2.8 Black Hole Entropy and Quantum Erasure.

So much of Verlinde's theory depends on Bekenstein's results for entropy on the event horizon of black holes, which ties directly into the holographic principle. All the information regarding the interior of the black hole is imprinted on the event horizon (E.H.) in surface area bits. These bits are Shannon entropy, regarding the degrees of freedom of the microstates of the interior. The interior is not emerged from the perpective of an observer outside of the black hole. The two parts of the universe are causally separated and interactions between observers and the black hole are mitigated by interacting with the event horizon, as a holographic screen. At the heart of this emergent theory lies the black hole information paradox.

Matter that gets pulled into the black hole is converted into bits of entropy, and increases the surface area of the horizon by a certain number of

[16] Are the bits on/off switches for Topological punctures in the holographic projection screen as indicated by Majumdar. Black Hole Entropy and Quantum Gravity. p.9?. Then the entropy of one cell is one bit of information (since the cell can contain a puncture or not). If these are punctures, perhaps homology theory comes into play here. Spin networks are also relevant here.

bits. Regarding matter that gets pulled into the black hole, the particles' information become entangled with the surface area bits on the event horizon. As the time slows down when the particle approaches E.H. asymptotically, the particle is being converted into information, and imprinted on the event horizon in a holographic way. This injective correspondence with the interference of the world lines of the particles onto the holographic screen respects time reversal symmetry. There is enough storage to accomodate this information because the surface area increases by the number of bits required to make a holographic recording of the incoming particles.

The causal disconnect between regions generates Hawking radiation. The issue is that as the black hole evaporates into Hawking radiation, this erases information, which was previously thought to be a conserved quantity. One thought is that if you could collect all of the radiation one could run it through a quantum computer to recover the information. I am going to propose that instead, irreversible quantum erasure is a feature that should be incorporated into the foundation of Q.M., if it has not been done so already. Furthermore the heat generated by erasure should be equivalent to the heat generated by the Hawking radiation.

The black hole information paradox is related to the Q.M. measurement problem in the following sense. It is proposed that measurement of an observable irreversibly erases the other potential world paths of the previous quantum state, that prior to measurement was a superposition of world paths. What this means is that measurement should generate some erasure heat. This heat should be experimentally measurable and comparable to the temperature without collapse of the same quantum state, and there will be an experimentally verifyable difference in heat with or without collapse. This makes an experimentally verifyable condition to test this variant of emergent gravity, provided that information erasure is incorporated into Q.M. foundations, and used to explain the measurement problem. This essentially rejects the Copenhagen interpretation. Unruh temperature has already been measured. It is proposed that the Unruh temperature is generated by a causal disconnect between regions, which irreversibly erases certain potential world paths through phase space. Thus the Unruh radiation could be the same as erasure heat. Erasure is a type of measurement, which dissipates heat, and with heat dissipated in the form of Unruh radiation, there is a corresponding force, which does work on the particle.

A superposition has a certain amount of Shannon entropy (measured in bits, or in thermodynamic quantities), and measurement changes the information of the quantum state, which dissipates heat. Measurement is irreversible, because it changes the entropy of the quantum state. Unruh and Hawking radiation are almost the same thing because they are generated by causally disconnected regions of spacetime, which causes the creation and anihilation operators of the vacuum to go slightly out of synch. Causal disconnects (and horizons) erase worldlines, which dissipates heat, which can be converted into mechanical work on particles as the entropy of the system changes.

Quantum states cannot be cloned. However, they could be holographically converted into information and stored on qubits. The information could later be projected, relative to the observer frame, via a mechanism similar to a quantum teleportation algorithm. This can account for time reversal symmetry of the information going into a black hole. However, the information is only reversible until the time that it is erased by being converted into Hawking radiation. Once it is converted into Hawking radiation, the information is irreversibly erased and the symmetry is broken.

From an observer outside of the black hole, the information regarding the matter going into the black hole is stored as entropy on the event horizon. If an observer crosses the event horizon, then the interior is projected, rendered from the qubits, as the information about the microstates of the interior becomes accessible to the observer. Upon crossing the event horizon, the hologram of the interior is rendered relative to the observer frame.

The event horizon acts as the holographic screen mediatior between the microstates of the interior and the outside of the black whole which is emerged of which the two regions are causally seperated.

3 Verlinde's Emergence.

This section will go deeper into the Verlinde model for gravity itself[17]. It relies heavily on the 1st and 2nd Laws of Thermodynamics as well as a polymer that is modified from the polymer model in §2. The Holographic Principle is also explained in §2.

In the simplest model, you can consider a spherical planet with uniform matter density, and a single Hydrogen atom being acted on gravitationally by the planet. Next, imagine the spherical surface with the planet in the center, and the boundary of the surface ∂V, is nearby the Hydrogen atom. Because

[17]Primary Source: Verlinde (2011). On the Origin of Gravity and the Laws of Newton

the density of the planet is uniform, the spherical surface ∂V will be at the same temperature T throughout. Recall that $T = \partial E/\partial S$ can be thought of as a conversion factor between energy and information, and that heat can convert information into mechanical work as the entropy changes. It is in this sense that gravity is considered an entropic force. ∂V is considered a reservoir, or "heat bath", that is able to exchange energy with the Hydrogen via an exchange of information[18](The bulk itself is the spherical volume V, which contains the matter of the planet). The information about the enclosed matter energy (of the planet) is stored on ∂V at temperature T.

In the case of attractive Newtonian forces, the force vector should point toward the potential source. The particles being acted on by gravitation is near ∂V. In the Verlinde model, the field is an emergent property of the thermodynamic system, and whatever forces are being experienced by the particle are entropic. In classical Newtonian physics, the enclosed matter (within V) would be generating the gravitational field. In Verlinde's system, the particle is interacting with the information on ∂V, and the entropy is powering gravitation in such a way. This is not vague in the article. Equations (3.6-7) makes this explicit, the energy of the enclosed matter is stored as information on the boundary. ∂V is acting as the reservoir of heat.

The field exists, and is manifested by doing work on the particle, however it is emergent, as opposed to acting directly via Newtonian forces. The Newtonian force is a derived quantity, from the thermodynamics, as an approximation.

3.1 Polymer Analogy.

Verlinde proposes that gravity is like a polymer in the sense that gravity is an entropic force.

In the model, the rubber band in the heatbath pulling on an attached mass is the analogy for the entropic force of gravity acting on the particle. The heatbath, plus the polymer, plus the mass are a closed energy system. In the analogy, this is ∂V information interacting with the particle nearby the surface via an entropic force.

What is consistent with the polymer model from §2, is we have an entropic force acting on a mass.

[18] ∂V acts as the reservoir, however we are dealing with Planck scales at high energy, so the total energy of the reservoir E must be regarded as finite.

3.2 Thermodynamics.

The entropic force acting on the particle mass near ∂V is modelled in units of work $đW = -Fdx$, where the force $F = -\left(\frac{\partial E}{\partial x}\right)_S$. An entropic force does not have to be a polymer[19]. It is simply the force acting on the particle near ∂V, on a one-dimensional line, from the heat bath of ∂V. A force acting over units of distance does mechanical work. The first law is $dE = TdS - Fdx$.[20]

By saying that $Fdx = TdS$, this is saying that $dE = 0$. When the force acts over a displacement Δx, the energy within the system is conserved, $\Delta E = 0$. Most importantly, Verlinde's model must be a **closed energy system**. In this particular context of a closed system, E must represent the total energy, including the reservoir, as well as the energy of gravitation itself acting on the particle. The second law then states that the entropy must increase until it reaches equilibrium $dS \geq 0$. So long as the total entropy of the system goes up, the entropic force does work on the particle, pulling it towards the screen, and then absorbing it into the screen.[21] The total entropy S must also account for the total entropy of the closed system. The system is microcanonical when taken as a whole.

3.3 Force Vector and Directions.

I put the origin on ∂V itself, with the axis pointing towards the potential source, such that $\vec{F} = F\hat{r}$. The axis is the ray connecting the particle to the potential source, with the origin being the intersection of that ray with ∂V. One could have the arrow pointing the opposite way, and it would just reverse the sign of the force $\vec{F}$ and the displacement $\Delta\vec{x}$, so the following analysis would come out the same, because it would constitute two sign reversals on the same side of $\vec{F} \cdot \Delta\vec{x} = T\Delta S$.

In the case where the particle is being sucked into ∂V, we have $\vec{F} \cdot \Delta\vec{x} > 0$,

[19] The physical mechanism of entanglement pressure being made manifest by converting information to work should be made explicit in future articles. The particle acts as an observer of ∂V which changes the entropy on the bits. Landauer erasure heat provides a theroetical minimum of heat flow.

[20] It is consistent with conventional thermodynamics to regard the energy representation as equivalent to the entropy representation. Verlinde's (2.3) is that $\frac{\partial S}{\partial E} = \frac{1}{T}$ and $\frac{\partial S}{\partial x} = \frac{F}{T}$. In other words $dS = dE/T + Fdx/T$.

[21] This should be accounted for in §5 by $dN \neq 0$.

siince the system is closed, $\Delta S \geq 0$. By examining signs, we deduce that the force is in the same direction, aligned, with the dispacement:

$$\vec{F} \cdot \Delta\vec{x} = T\Delta S \geq 0 \tag{3}$$

Also, note that the vector notation has been added to the Verlinde model by us, and did not appear in the original version.

3.4 Partition Function.

In the canonical ensemble, we assume that a sub-system is in thermal equilibrium at constant temperature T with a heat-bath. $\beta := \frac{1}{k_B T}$. For a particular energy E and position X, the entropy is $S(E, X) = k_B \ln \Omega(E, X)$. The quantity of microstates with differentials $dEdx\Omega(E, x)$ acts as a density of states. The system is taken as canonical when the gravitation is a sub-system. As a subsystem, the particle exchanges energy with the heat bath. A canonical ensemble is derived from the microcanonical ensemble as a closed energy system. The temperature is powering gravitation by the particle exchanging energy with ∂V.

Verlinde (2.2) is the partition function for the canonical ensemble:

$$\mathcal{Z}(\beta, F) = \int\int dEdx\Omega(E, x)\exp\{-\beta(E + Fx)\}$$

One concern that is raised is that this partition function is only valid for very small intervals of x, otherwise the force F would certainly vary. When it is integrated over Compton wavelengths, $\Delta x \sim \frac{\hbar}{mc}$, it should be about right: $\int\limits_{-\Delta x}^{0} \int dEdx\Omega(E, x)\exp\{-\beta(E + Fx)\}$. It is valid in the article when it is used to explain what happens when the emerged particle is very close to the ∂V, but perhaps not later in §3.3 when he moves the ∂V further away, to R_0. However by then we do not even neccesarily have equipartition, so it may not even matter (planning to discuss some details and concerns of this part later). This is what I mean when I say that a particle is "nearby" ∂V.

Nevertheless, if one applies an external force over a larger interval of x, it pulls the system out of position equilibrium. If $-F(x)$ is the external force required to keep the system at a new position equilibrium x, then this charges the potential energy of the subsystem: $U(x) = -\int dxF(x)$. The entropic force is equal and opposite to the external force, $F(x)$. When you release the external force, the entropic force pulls the system back towards position equilibrium. At position $X = x$, the total energy of the system is $H = E + U(x)$. The entropic force is $\vec{F} = -\nabla U$. We arrive at a slightly modified version Verlinde's (2.2) partition function for entropic force:

$$\mathcal{Z}(\beta, F) = \int \int dEdx\Omega(E, x) \exp\{-\beta(E + U(x))\} \tag{4}$$

For most of the instances that I am using this in this paper, either versions of $\mathcal{Z}$, either the above equation or Verlinde's (2.2) can be utilized. It is important to note the limitations and assumptions aforementioned in this sub-section.

3.5 Compton Wavelengths.

An important note is Verlinde puts the displacement (3.1) at exactly one reduced Compton wavelength from the holographic projection screen, $\Delta x = \frac{\hbar}{mc} = \ell_C(m)/2\pi$. This is an ontological position that displacement step sizes are quantized in such a way. Integral units of displacement correspond to one finite discrete unit of entropy, $\Delta S = 2\pi k_b$. The scale factor of entropy units is almost arbitrary, and in the sense of maximization at equilibrium, indeed the scale factor should not matter much. Since we are working mostly in thermodynamic units, it is not surprising that a step-size of entropy is proportional to k_B. The step units for the Compton resonance, on the other hand, is fundamental, and denotes a quantum structure of reality itself, not limited only to gravitation. The importance of this ontological statement is not emphasized much in the article. Indeed the whole derivation of gravitation rests upon this as an assumption. I can provide some justification, and we can also treat it axiomatically as it is in the article.

For light signals coming from the center of V and undergoing Compton scattering against the particle of mass m, Δx would be proportional to the shift of the impacting photons' light wavelengths, $\Delta x \ \alpha \ \Delta\lambda_\gamma$. This is further evidence that Δx is an optical quantity.

The holographic screen should be located on a surface ∂V that is an optically coherent distance from the particle. This has the corresponding dimensional reduction of the particle on the surface/screen, in accordance with the holographic principle. The degree to which a particle exists on a particular screen is the degree to which its world paths are coherent. Therefore, it makes sense to put the particle at an optical wavelength away from the screen (reduced Compton wavelength).

The quantum bits are spaced out in a grid of Plank lengths ℓ_P. The partical being acted on by gravitation moves in increments of reduced Compton wavelengths $\alpha\ell_C$.

The coherency of the quantum frequencies on the surface is allowing the particle to read-off information on the screen, thus affecting it's entropy. In this sense, the surface qubits are acting as an observer of the particle, and vice versa. Changing the information changes the entropy. The changing of entropy leads to thermodynamic work. The particle's frequencies are thus becoming entangled with the qubits on the surface. The entanglement pressure is the mechanism via which gravitation acts on the particle (It is not a polymer).

If you divide out the displacement into unity, you arrive at the entropy step-size of [Verlinde](3.2): $\Delta S = 2\pi \frac{mc}{\hbar} \Delta x$ as a differential of the step-size in displacement.

3.6 Newtonian Gravity from Emergence.

This is shown in the Verlinde article. I am adding some of the algebra steps for the readers, but I do not wish to insult the reader with how simple this derivation is now that we have all of the relevant equations in place. From [Verlinde] (3.2), I re-arranged to have the entropy derivative with position: $\frac{\Delta S}{\Delta x} = 2\pi mc/\hbar$. Then, from the 1st Law $F\Delta x = T\Delta S$, solved for the entropic force:

$F = T\frac{\Delta S}{\Delta x} = 2\pi Tmc/\hbar.$

Next, where the surface area of ∂V is $A = 4\pi R^2$, recall the number of bits on the screen is $N = \frac{Ac^3}{G\hbar}$. Then, M is the amount of mass inside the bulk V (not emerged). We have two expressions for the same amount of energy, the rest-mass energy from Relativity, and the equipartition of that same energy stored on the qubits: $Mc^2 = E = \frac{1}{2}Nk_BT$. Substitute the number of bits N and the surface area A into the energy equation and then absorbing that into the entropy derivative:

$$\frac{1}{2}\frac{4\pi R^2 c^3}{G\hbar}k_B T = Mc^2 \rightarrow M = \frac{R^2}{Gm}T\frac{\Delta S}{\Delta x} = \frac{R^2}{Gm}F$$

Finally, solve for the entropic force F, and see that it is equal to the Newtonian gravity force F_{grav}: $F = \dfrac{GMm}{R^2} = F_{\text{grav}}$

4 Resolving the Polymer Analogy.

4.1 Concerns Raised with the Polymer Analogy.

I have not been the first to notice that the particle undergoing gravitation with a surface has issues with being a polymer in a heat bath in a more literal sense, in particular we have Saun Gao[22]. However, my conclusions differ significantly from his.

Much of Verlinde's second section is based on a polymer model. I need to point out how his version of the polymer differs from the usual model (presented in Section 2). The internal energy U will typically refer to the subsystem of the polymer itself, which interacts with the heat reservoir as an open sub-system. Thus, the entropy of the rubber band is allowed to rise and fall accordingly, since heat flows across the subsystem boundary. However, it is crucial to note that the total entropy of the reservoir with the polymer [as a combined system] either increases, or remains constant. This is driving the elastic force, which is entropic, towards equilibrium, at which point the total entropy of the combined system is maximized.

I reiterate that Verlinde's energy E refers to the total energy of the combined system, and is a closed system. This is required in order to say that $0 = dE = TdS - Fdx$, in order to arrive at [Verlinde] (3.3), which is to say that the heat balances the mechanical work: $TdS = Fdx$. This is contrasted with the energy of the polymer U.

This is predicated on the assumption that the particle is literally a polymer. It probably should have been made explicit if this is merely an analogy or are we are making the claim that gravity is a polymer. I am going to make the claim that based on a number of considerations we cannot regard the particle/surface interaction as a polymer. Thus, beyond regarding it as an "entropic force" (whereby the results from section 2 can still be maintained

[22]Saun Gao. Is Gravity an Entropic Force? 2010

with care), the specific mechanism for interaction becomes somewhat vague in the 2010 version[23]. We run into trouble almost immediately when looking at the details of the polymer model. Firstly, in Callen's model $\delta U_y = \varepsilon$ and $\delta U_x = 0$. This is to say when a monomer link goes vertical, the energy increases by one increment and the horizontal monomer links contibute zero energy. Callen justifies this by saying that the polymer "suffers interference" (bumps into?) from other polymers. However, why are there no forces in the y direction, indeed $\mathcal{F}_y = 0$. On the contrary we have force in the x direction, $\mathcal{F}_x$, which somehow do not affect the internal energy (by way of individual links and charging the potential). One could perhaps think of the x direction links as a sort of ground state, this seems to become increasingly convoluted when you then try to think of a particle as a bundle of rubber band polymers or a plastic of some sort. An entropic $\mathcal{F}_x$ does indeed emerge if you make these assumptions, and those equations make sense (only if you make these assumptions). However, I do not see how these assumptions would apply meaningfully to the particle/surface interaction. If you examine Verlinde's (2.2) partition function once again, you will see right away that the force does, in fact, factor into the energy with work done along x. Contrastingly, in the polymer, the x links factor into the energy seemingly only indirectly in the fact that they take away an available link from y with which to raise the energy by bumping into other polymer strands.

4.2 The Polymer Engine and Causation (Solving Gao's Concerns).

Emergent gravity is "like" a polymer in that it is an entropic force, but not all entropic forces need to be a polymer. The more general, entropic force acting along $\hat{r}$, and information changing on a surface ∂V at temperature T, still applies.

Where my opinion differs from Gao's is that he seems to be under the impression that the consideration that emergent gravity cannot be a polymer, along with a number of others are fatal to emergence. He comments that the energy of the screen increases. Indeed when ∂V absorbs the particle, we have $\delta E_m \approx mc^2$, which is the absorbtion of the particle mass into the

[23] To describe the mechanism of interaction between the surface and the particle, this will lead inevitably to quantum foundations considerations. We can think of it as an "entropic force", just not a rubber band.

screen. Energy leakage is indeed a serious issue, which rears its head again later in another section, which does not appear to have been commented on yet. However, to my mind, the leakage is not fatal to emergence, it simply means that the system is not yet closed. I attempt to close the system in the next section, and once the system becomes closed, there is no longer such an issue.

An engine converts heat to work at the efficiency of η, in a causal way, tracked by the entropy, and also as an open energy system. The particle/surface system being open, and the system not being a polymer, is not the death of emergence, it merely needs to be modified by extending the system boundary, as well as making explicit which subsystems are open (which are incorrect in the 2010 version as I argue in another section). Now, the causal picture of heat (entropy) flow, when it is contrasted with the statistical model of entropy as an order of magnitude of available microstate configurations, in thermal units (k_B). Here some confusion arises as another of Gao's valid critiques of emergence. Since the energy is changing, he says that the entropy changing is caused by the energy changing, rather than the other way around (i.e. that the entropy is causing the gravitational field is called into question). The causal relationship between quantities is indeed a valid issue, again I do not see it as fatal. Nor do I see it as neccesarily pointing in the direction of the energy causing entropy, rather they are correlated rather strongly in the statistical mechanics (in both directions). The first law applies whether the system is open or closed. In the case of an engine, there was little doubt that the heat is compelling the pistons to move. Upon further and further study it becomes more a study of variance which defies a direct cause-effect relationship. There is little doubt that the entropy models conversion of thermal energies into other forms.

This points out a flaw in the thermodynamics itself (or just something that needs to come to terms). In the fundamental entropy representation 1st law: $dS = \left(\frac{\partial S}{\partial E}\right) dE + \left(\frac{\partial S}{\partial x}\right) dx = \frac{1}{T} dE + \frac{F}{T} dx$. And in the fundamental energy representation: $dE = \left(\frac{\partial E}{\partial S}\right) dS + \left(\frac{\partial E}{\partial x}\right) dx = T dS - F dx$. The confusion comes in only slightly that these are regarded as fully equivalent. The major confusion is that you have the extemporaneous flipping of causal partial derivatives and that this somehow means something to the effect of dE being a cause or dS being a cause etc. This is right there at the foundation of stat. mech. No one is saying that thermodynamics is broken and everyone should just go home. On the contrary, it remains as an effective tool for modeling **emergent** phenomena.

4.3 Verlinde's Extention to Gravity.

This is also a summary from §3. A number of important points to note in Verlinde's model which can be claimed in spite (or independently) of the polymer model:

1. The closed surface ∂V is the heat reservoir.
2. The energy E refers to the energy of the entire system, which includes ∂V (reservoir).
3. The entropy S is also reffering to the entire system.
4. This system is micro-canonical, and only canonical when the particle is considered a sub-system.
5. The temperature is being supplied by the Unruh temperature.
6. The temperature is powering gravitation as an *entropic force.*
7. The energy system of the reservoir acting on the particle is closed.

5 Other Concerns about Verlinde.

5.1 Arrow of Time - reversal symmetry.

If you consider that Δx and ΔS are time-odd quantities, for example entropy increases when you reverse time. There was some concern that this would lead to the force pointing in the wrong direction when you reverse time in the Verlinde 2010 model. I found that there was not an issue with the force changing direction.

Gravitational force is a time-even quantity because it points in the same direction when you reverse time.

Supposing $\vec{x}_f - \vec{x}_i = \Delta\vec{x} = \frac{\hbar}{mc}\hat{r}$, running this time-odd quantity backwards in-time yields a negative displacement, $\Delta\vec{x}' = \vec{x}_i - \vec{x}_f = -\frac{\hbar}{mc}\hat{r}$. The particle moves backwards from the direction it came.

Similarly, entropy increases moving forward in time, by bits in thermodynamic units: $\Delta S = 2\pi k_B$, so that reversing time, the entropy decreases:

$$\Delta S' = -2\pi k_B = 2\pi k_B \frac{mc}{\hbar} \Delta x'$$

Originally, we have:

$$\vec{F} \cdot \Delta \vec{x} = T \Delta S > 0$$

This indicates that $\vec{F}$ points in the same direction as the displacement $\Delta \vec{x}$.

Then, reversing time:

$$\vec{F} \cdot \Delta \vec{x}' = T \Delta S' < 0$$

One sees that $\vec{F}$ points opposite to $\Delta \vec{x}'$. So, although $\Delta \vec{x}'$ reversed direction, the force arrow did not.

We quickly confirm that (3.5) (Newton's 2nd Law) still holds. The Unruh temperature is:

$$T = \frac{1}{2\pi} \frac{\hbar a}{k_B c}$$

Solving for the force:

$$F = T \frac{\Delta S'}{\Delta x'} = \frac{1}{2\pi} \frac{\hbar a}{k_B c} 2\pi k_B \frac{mc}{\hbar} = ma$$

5.2 Issue of Displacement Reversal.

There is an issue with signs, that has not been addressed previously. Here I show that ∂V and particle must be an open energy system. Although the entropic force passes the time-reversal test, there is a problem with signs in the case that the particle is moving away from the source of potential, $\hat{r} \cdot \Delta \vec{x} < 0$. If we insist that the 2nd Law of thermodynamics applies, the entropy should increase when moving forward in time, i.e. $\Delta S \geq 0$:

$$\vec{F} \cdot \Delta \vec{x} = T \Delta S > 0 \tag{5}$$

In this case the force should point opposite to the displacement (towards the potential source), however by examining signs, we see that the force is aligned with the dipslacement. The force points in the wrong direction for Newtonian gravity. This is an example of anti gravity.

The only conclusion is that heat must be flowing off the surface and into the ambient space, in order to loose entropy. The surface and particle are actually an open energy system. In the case where the particle is moving away from the surface, $\Delta S < 0$, and heat must be flowing off the surface, $\delta Q = T\Delta S$. This flow of heat is converted into mechanical work on the particle (lowering its kinetic energy). *The previous model is leaking energy.*

$$\vec{F} \cdot \Delta\vec{x} = T\Delta S < 0 \tag{6}$$

Here this is traditional Newtonian gravity with the force anti-aligned with the displacement, and pointing in the correct direction.

5.3 Causal Heat.

As far as potential resolutions, I would argue that in order to resolve the issue with signs, the surface/screen moves with the emerged particle. This is the argument that absorption of the particle into the holographic screen is entropically favoured. If the particle is moving away from the potential energy source, then the holographic screens are expanding with the motion (the particle is emerging from them). From the perspective of the particle, the screens are spherically symmetric, and co-centric. This causes the particle to slow-down and loose momentum. From the perspective of a screen, once the particle looses its momentum and reverses direction towards the potential source, it gets absorbed into the screen and converted into entropy. It is no longer emerged from that point of reference (everything about the volume V interior is information on the surface area, and each pixel bit has a temperature). From the reference of the particle, there is a discrete progression of holographic screens as the particle moves.

The issue with signs can be resolved by reinterpreting the location of screens and the meaning of the quantity Δx, not as the displacement of the particle, rather as the distance of that particle to the particular holographic projection screen from which it is emerged (projected). This would be the displacement of the particle if there were no other inertias other than the absorption into the projection screen itself (the entropic force).

Integrating over arbitrary screens does not even make complete sense without much further consideration. Concerns were raised recently in Wang and Braunstein (2018) *Surfaces away from horizons are not thermodynamic*

[24], which further supports the claim that the emergent theory does not follow directly by integrating over completely arbitrary holographic screens. One may recover the theory by carefully selecting screens that are thermodynamic. In our case, when the screens are spherically symmetric, there is not an issue here, yet.

One should in-theory still be able to build a nesting-doll type of structure for the screens, and the success of the theory in its current form can be not only rescued, but improved.

$\delta E_m = \mu \Delta N \approx mc^2$ The energy of absorbtion of the particle into the surface. μ is the particle pressure[25], often referred to as a "chemical potential". When the particle is absorbed into the surface, this μ changes the number of bits of information on the surface accordingly, and also expands the surface area accordingly, which then pushes the volume of the region out, and applies pressure, expanding the space.

Heat is flowing off the surface and into the next surface, concentrically/radially outward when the gravitating particle looses kinetic energy. If the particle gains kinetic energy moving towards the surface, then the entropy of the surface can increase as the particle is pulled into the surface, and absorbed. The heat is converted into mechanical work, either gravitating the particle, or expanding the volume of the surface, applying pressures. Once all of these forces are tracked and accounted for, we have the 1st Law:

$$0 = T_1 dS_1 + T_2 dS_2 - PdV - F_{\text{grav.}} dX + \mu dN \tag{7}$$

P is the pressure of cosmic expansion, and varies by region. This closes the system, in the simplest model of one particle and uniform matter density, $T_1 < T_2$, and even in the unsimplified model, $\Delta S_1 + \Delta S_2 > 0$. One can see how the varying Unruh temperatures could lead to a flow of heat between surfaces, and that this is driving both gravitation, as well as expansion. And, not only is gravity thermodynamic, but also expansion is accounted for even in the Newtonian approximation under thermodynamic considerations.

With these modifications to emergent gravity, I predict an an-isotropic cosmic expansion as a correction to the Einstein field equations. The endo entropic heat flowing off of the screens, and the expanding surfaces from the increasing bits from absorbtion, can reasonably be regarded as dark energy.

[24] Nature Communications. `https://www.nature.com/articles/s41467-018-05433-9`

[25] I think of this as the number pressure in the context of bits, but this is not needed.

The changing entropy of the gravitational thermodynamic system as a whole (at the Unruh temperature) can be regarded as “causal heat.”

The diathermal, movable, and permeable partitions are the holographic screens. The irreversible entropy increase is due to regions of the universe that cannot communicate with each other causally.

6 Future Work.

To further explain the entanglement pressure, I propose a retrocausal solution to EPR that includes quantum erasure. When further elaborated, this also fully resolves the black hole information paradox (essentially the Hawking radiation is the heat of erasure of the lost information), as well as providing at least some insight into the measurement problem (the other bits of entropy on the quantum state are converted into information, but then the other timelines of the state must be erased to do so, which dissipates heat.

So far I have not seen an explicit equation written out for the dimensional reduction, which I hope to attempt in future work (See the following subsections for a description of my plan).

I plan to eventually make use of the course-graining/renormalization from QFT, and treat the resolution as a degreee of freedom of the system. I can make this more explicit in future articles. I also wish use anti de Sitter and conformal field theory dual correspondence, in the original article this is left somewhat vague.

Eventually in future work, I want to tie-in polyhedral triangulation and use parts of loop quantum gravity, and even causal set theory. Also, bootstrapping what is known about cellular automaton as a model for how bits are conveying information, indeed this may tie into causal set triangulation (CST). All of these details seem vitally important, in my mind, to the theory (how are the bits conveying information).

I want to look into open and closed strings as they pertain to photons and gravitons[26].

Another plan of mine is to continue the research I started on the “Tensor Polytope”[27], by looking for quantum gravity applications and attempt to

[26] Conversation with Naina Tyagi.

[27] Dynneson. Tensor polytopes, Hom polytopes, Hyper-matrices, and data clustering (2014).

recover a continuum by taking tensor products of polygonal 2D pixels and therby constructing a polytope[28].

I wish to discuss at length how accretion acts like a gravity engine operating at efficiency η, via angular momentum transport, sending gravity centrifugally outward at the same time as pulling matter centripetally inwards. This is another useful model, which I would like to attempt to apply to spinor theory, of which the centrifugality of quantum gravity has been commented on by Marcus Cohen[29]. Within the same article, Cohen says probability amplitude waves are physical. Tying this into the more recent emergent gravity, what this could mean is that a spinor is physical because the probability contributes to entropy, which in turn affects temperature and energy, from which emerges the mass.

We have already commented extensively on the epistemiology of the uncertainty measurement itself[30], there are many loose ends to tie up there, some of which tie into quantum gravity, especially under information-theoretic considerations, as we have proposed an informational realism re-formulation of Calculus.

6.1 Holographic Storage and Projection.

Planck area units are the theoretical minimum for qubit storage. The number of bits certainly scales with the surface area with which the qubits are stored. The bit units also depends on both the boundary conditions and the frequency modes. The more frequency modes, then the tighter the surface area bits, with the Planck areas being the theoretical minimum by the uncertainty principle. Planck area units represent the maximum possible information density on the holographic storage medium. In the case of black holes, in order to absorb more information for incoming mass elements, the surface area of the event horizon would need to increase to accommodate the information absorbed from the interfering (coherent) waves. Each continuum point within a surface area bit $\vec{y} = (y^1, y^2)$ is representative of the equivalence class of that particular bin/bit. The individual continuum points within the bin/bit do not have physical meaning and the holographic storage system is quantized. The pixel resolution is a degree of freedom for the stor-

[28] Note that the Stochastihedron was discovered well after I archived my article on Tensor Polytopes.

[29] 8-Spinor Quantum Gravity (2002).

[30] Dynneson and Alvarez. Infinitesimal Calculus as an Epistemic Mediator (2016)

age system, which will depend on the number of interfering frequency modes and corresponding uncertainty.

The issue of both time-reversal symmetry and information preservation on black holes (as well as causal horizons) is resolved by the projection of the stored holographic information both to and from the medium of storage. This is the explicit construction of the dimensional reduction of the emerged space. This is the holographic principle applied to causal horizons. The absorption of particles is reversible via the injective storage of the interfering world-path information near the horizon. The holographic storage mechanism also denotes the means with which the hologram could be projected from the medium if time were reversed [31].

6.1.1 Matter Waves.

Recall that when the position quantum wave function is Fourier transformed to momentum space we have:

$$\langle \vec{x}, t| \, |\phi\rangle = \sum_{\vec{k}} f(\vec{k}, t)\hat{a}_{\vec{k}} + f^*(\vec{k}, t)\hat{a}^{\dagger}_{\vec{k}}$$

This is a superposition of all possible positions of the particle, weighted by probability amplitudes, as well as accounting for the relative phases. Near the horizon, the phases of the particle should be coherent, so as to provide constructive and destructive interference which are stored on the horizon, acting as a holographic storage medium (referred to as a grating).

Only in the case of Minkowski space is the momentum basis for the matter wave $f_{\vec{k}}(t)\alpha \exp i(\vec{k} \cdot \vec{x} - \omega_{\vec{k}} t)$ nearly identical to that of a light-wave optical interference pattern, which can be stored holographically on a grating, and these equations are well-known. This should be reverse-engineered to account for:

1. The curvature of the storage medium (the grating is only locally flat)
2. The curvature of the ambient space near the horizon

[31] It is reasonable to suspect that the vacuum state is the reference beam however I should provide further justification.

6.1.2 Holographic Medium

In the Newtonian or possibly even the semi-relativistic approximation, the flat Minkowski space should suffice, but other curvatures should be accounted for in the final version of this theory, wherein the dimensional reduction from (3+1) to (2+1) is finally made explicit. The hologram is recorded on the horizon via interfering coherent waves (forgot where I found this figure).

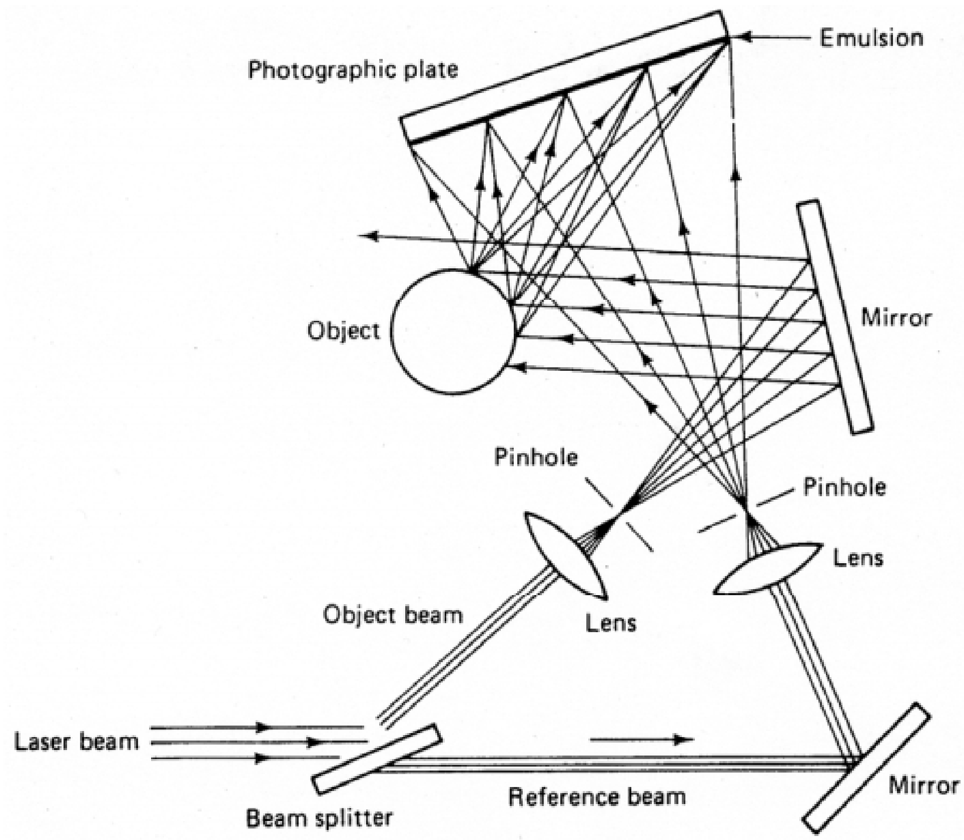

Figure 11-1 Basic optical system for producing holograms.

Then, the hologram is recovered by[32]:

$$\tilde{E}^t_P = \tilde{C}(t)\sum_{n=-\infty}^{n=\infty} i^n B_n(\phi_0)\int_{\text{grating}} exp\{i(\vec{y}\cdot(\vec{k}\sin\psi_1 - \vec{k}\sin\theta + nk''))\}dy^1dy^2$$

[32]Toal, Vincent. Introduction to Holography. CRC Press. p.72 (Section 3.2.2)

$B_n(\phi_0)$ is the Bessel function of the first kind on the phase-shift ϕ_0 of the recording, angles ψ_1, θ, coefficient $\tilde{C}(t)$, and the k'' term are made explicit on p.72 of the reference.

7 Appendix

7.1 EPR.

The qubits on the holographic screen are entangled with the emerged particle. This can reasonably be viewed as entanglement-pressure, and the physical mechanism by which the screen exterts influence on the particle.

More generally we consider producing an entanglement of two qubits $(|+\rangle + |-\rangle) \otimes (|+\rangle + |-\rangle) \mapsto |+-\rangle + |-+\rangle$. This is in the sense that entanglement is the erasure of the microscopic geometric (tensorial) structure. Information increases by applying energy and making a measurement via the Hamiltonian, which reduces the entropy of the state vector. Time-evolution then recovers the entropy, by an increase in uncertainty (for example, in position). The resolution of the position-hologram is reduced when the resolution of the energy/momentum hologram is increased, and vice versa. There is a fundamental limit on the resolution of the combined phase-space hologram. In this sense the course-graining of the system can be thought of as having a physical effect on the macrostate itself. The structure is also observer-dependent, with relative frames for different observers. Observers experience inter-subjectivity. When observers communicate, it affects the information that is conveyed. Observers that communicate information are also entangled with eachother. An observer that has not communicated yet is still having a physical affect on the information that is being observed, however the observer is stored as a superposition of what is possible for him to observe to all outsiders that have not communicated with him yet. The potential of communication is on the future light-cone. The communication of the observation to the outsider is already stored on the information. The future event is thus contained within the information of what is possible to have been observed (in a superposition) in the past, and communicated in the future via a collapse of that superposition. The relaying of information is physical, but it is relative to the observer reference-frame. Qubits can store all the entropy of what is possible to happen in the future. Without the potential to communicate the information, the information simply does not exist for the observer outside the light-cone. It can never be read, therefore it can only exist as thermodynamic/Shannon entropy. The only thing that can exist for an observer is what is possible to be an outcome of some measurement. But where are the qubits, and what is the nature of the information stored there. Everything that is possible to have happened is stored on the qubits until it is read, and then it falls into an eigenstate of the observable, whatever that observable that is measured. For example, a singlet state is entangled qubits to the outsider. But to a Stern-Gerlach machine, it has a definite spin after measurement. To all outsiders, the spin of the 2nd particle remains in a superposition until you either communicate with the Stern-Gerlach observer, or measure it yourself. The two ways of acquiring the information (and lowering the entropy), either communicating or measuring are actually equivalent. If you are capable of neither, the information does not exist for you, it is as though the event never happened.

Information is physical. There is no spooky action at a distance. It is merely that the information is stored on the qubits, and where the qubits are located in space-time is an artifact. The spatial coordinates are projected as a hologram, they are emergent. The information about the qubits are stored in the qubits, not the spatial coordinates. How the information is viewed (and by whom) is likewise stored on the qubits, thus the observer is entangled with what he observes. The observation and subsequent collapse of the state vector might be stored retrocausally on the original state vector, and that is why spatially separated observers always correlate in an inter-subjective way.

The pixels are determined by 1) the information contained in the medium, 2) The measurements that you perform on the stored data/information. The hologram is projected post-measurement. Post-measurement the information is stored on the boundaries of the pixels. Prior to the measurement where is the information stored? Are the pixels not determined by the outcome of the measurements....(Entropy on a holographic screen pre-measurement, whose resolution is filled-in post-measurement with information stored on the pixels). Is the medium of information storage not energy, what is the nature of energy if it is not programmed information. The medium of storage versus the medium of projection/viewing.

The observer is entangled with what it observes, what is observed, and how it is observed is stored in the qubit information. The observer's effect on the observed information is physical, this cannot be avoided. Increasing the information by reducing the entropy (in an open system) will always affect the energy.

The spatial coordinates are emergent from the information that is stored on the qubits. This is similar to (for example) a hologram being projected from a holographic screen. The real physical process is the information that is computed via the medium of interfering light waves. This is local. Meanwhile, the projection, while in the case of EPR may appear to be non-local, but this is merely an artifact, as all the physics are computed locally on the information qubits[33].

7.2 Maxwell's Demon.

Maxwell's Demon is the penultimate example of a mechanism which can convert information into mechanical work. Converting the information into work by knowing when to engage the partition then dissipates heat when the information is erased. Where my understanding differs slightly with the consensus model is that the demon must consume energy in order to first gain the information about the ensemble. Lowering the entropy requires energy crossing the system boundary $\delta Q = TdS$, this is the heat that is consumed when converting to work, moving the partition $\delta W = PdV$.

There need not be a conscious entity involved in order to perform this conversion of information (causal heat) into work. When a qubit entanglement is created, $(|+\rangle + |-\rangle) \otimes (|+\rangle + |-\rangle) \mapsto |+-\rangle + |-+\rangle$, this increases the information of the state vector, lowering the entropy. This dissipates Landauer heat. Gravitation then converts the dissipating heat into particle-work.

7.3 Entropy of a Black Hole.

With a black hole the location of the projection screen is clearly on the event horizon, with all of the information about the interior of the black hole stored on the event horizon. When an emergent particle approaches the screen and gets converted back into information, the screen area absorbs it and increases by the corresponding pixels (qubits). The area of the event horizon must increase to accommodate the inclusion of additional mass. In fact, the particle was always information, it was merely emerged from the information. Each pixel on the screen is a qubit of information. But where is the information stored, and by what medium is the information stored? The

[33] I may have gotten some of this idea from a Susskind article.

duality between information and energy does not fully resolve the mechanism by which information is stored. It is clear that information is emerged into the physics via energy, however the a-priori nature of the information itself remains vague. Is the black hole not a singularity, while dualistically, its interior is stored on its surface as information/entropy, and we are forever separated from its interior, without converting the observer likewise into the information stored (compactified) on the screen. If all of its mass is truly existent at the point singularity, then how is the nature of space understood in this sense? Whilest existing all at the point, and simultaneously on the screen? Are the two means of viewing the information not theoretically identical (as mass at a singular point vs. viewed as projected from a screen). If the observer enters the black hole, then the black hole interior is projected to his perception. To all observers outside the black hole, the observer that has entered the hole has been converted into information on the horizon (increasing its area, number of pixels, number of qubits), and no interior is ever rendered to the outsider. The observed is in a sense projected as a hologram, regardless of how it is viewed/perceived.