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Szilard Engine Reversibility as Quantum Gate Function

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ABSTRACT

A quantum gate is a logically and thermodynamically reversible situation that effects a unitary transformation of qubits of superimposed information, and essentially constitutes a situation for a reversible quantum decision. A quantum decision is a symmetry break, and the effect of the function of a Szilard engine is a symmetry break. A quantum gate is a situation in which a reversible quantum decision can be made, and so if a logically and thermodynamically reversible Szilard engine can be theoretically constructed then it would function as a quantum gate. While the traditionally theorized Szilard engine is not thermodynamically reversible, if one of the bounding walls of a Szilard engine were to be constructed out of the physical information by which it functions in such a manner as to make that information available to both sides of the wall simultaneously, then such a Szilard engine would be both logically and thermodynamically reversible, and thus capable of function as a quantum gate. A theoretical model of the special case of a reversible Szilard engine functioning as a quantum gate is presented and discussed, and since a quantum decision is made when the shutter of a Szilard engine closes, the coherence of linked reversible Szilard engines should be considered as a state during which all of the shutters of linked Szilard engines are open simultaneously.

Keywords: Szilard engine, symmetry break, thermodynamically reversible, logically reversible, quantum gate, nucleic acid

1. INTRODUCTION

A quantum gate is a logically and thermodynamically reversible situation that effects a unitary transformation of qubits of superimposed information, and essentially constitutes a situation for a reversible quantum decision. A symmetry break is a quantum decision, and if that symmetry break is both logically and thermodynamically reversible then it should be considered to be a quantum gate. The function of a Szilard engine is essentially a symmetry break [1], but a Szilard engine as traditionally theorized is not thermodynamically reversible because information would build up inside the engine and energy would need to be input to erase that information. [2] If a special case of a logically and thermodynamically reversible Szilard engine could be theoretically envisioned, then that special case should consequently be considered to be a quantum gate. This paper presents such a theoretical model.

A Szilard engine uses information to convert the energy associated with the entropic particle that it contains into the useful work of driving a piston [3], and the logical reversibility of a Szilard engine's function can be easily demonstrated as the reversing of the position of the piston after the action of the power stroke of the engine. Because all information is physical [4], the thermodynamic reversibility of a Szilard engine's function can be theoretically envisioned in a special case of Szilard engine that has part of a bounding wall constructed out of the physical information by which it functions, in such a manner as to make that information available to both sides of the wall simultaneously. [5] In such a theoretical situation it would be impossible for information to build up inside the Szilard engine and so there would be no energy cost necessary to erase any information that would build up inside it. Two or more of such logically and thermodynamically reversible Szilard engines could be coherently

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linked by their pistons, or by their information-containing bounding walls. A quantum decision could be considered to be made when the shutter of a Szilard engine is closed, and coherence of such quantum gates could be considered to occur during a time period in which linked reversible Szilard engines have their shutters open together. These concepts have a significant implication for the consideration of a potential theoretical quantum gate function within the information-containing nucleic acids of biological systems [6], and for the conceptualization of practical quantum logic system design.

2. REVERSIBILITY

The function of an engine is to produce useful work. An engine is logically reversible if the physical change in the configuration that produces the useful work of the engine can be reversed and the engine can be put back to the original physical configuration that existed before it produced any useful work. In the case of a piston engine such as a theoretical Szilard engine, this means that the piston would be able to be pushed back into its original starting position. So the information that would make an engine logically reversible exists external to the inside of the engine, and is in the form of the physical effects of the work of the engine.

The interior of a Szilard engine is by definition a closed system and as such contains a finite number of moving particles. The essence of a Szilard engine is that it uses information to convert the energy associated with the entropy of a moving particle into useful work. This happens as a theoretical homunculus inside the machine opens and closes a shutter to selectively admit the particle to one side of the partitioned mechanism while not allowing the particle to escape from that side. The homunculus does not need any information other than when to open and close the shutter for the engine to function. Note that the homunculus does not need to be able to sense or measure the particle; rather the homunculus only needs to know when to open and close the shutter. If the homunculus is given information about the position and momentum of the particle inside the engine, as well as information about the internal dimensions of the Szilard engine, then the homunculus could theoretically calculate the exact times to open and close the shutter without making any measurements of the particle. Because the number of particles inside the Szilard engine is finite, the information necessary to convert the energy associated with the entropy of those moving particles into useful energy is therefore also finite. If the information needed for the function of the Szilard engine (which is essentially the information about the timing of opening and closing the shutter) was given to the homunculus in writing and sealed inside the engine with the homunculus, then the homunculus would have all the information necessary to trap any particle and there would be no need to either input more information into the theoretical machine, or a need to erase any information that would build up inside the theoretical mechanism.

The process could be reversed if the homunculus were to open the shutter and allow the particle to reach equilibrium on both sides of the partition. Note that the initial information of the position and momentum of the particle and the internal dimensions of the Szilard engine could be used to calculate the continued trajectory of the particle throughout the entire cycle of the Szilard engine. Therefore concern about the thermodynamic reversibility of a Szilard engine can be overcome in a special case in which the information about when to open and close the shutter of the Szilard engine, or the information about the initial position and momentum of a particle within the engine along with the information about the internal design of the engine, is sealed in the engine and is available to the homunculus.

Consider a further special case in which the Szilard engine is physically constructed out of the information by which it functions, and in this further special case that information exists on both sides of the engine simultaneously. An example of how this can occur can be theoretically envisioned as a Szilard engine mechanism with at least one wall of the engine constructed out of a single layer of bricks and that the bricks could be in the shapes of letters and with mortar filling any gaps within or between letters so that there is no opening in the wall for a particle inside the Szilard engine to escape. The homunculus of the machine could read the information on the wall, and theoretically a second homunculus on the other side of the wall could also read (the reverse image of) the information, so the information in this case would exist on both sides of the wall simultaneously (but phase shifted by 180 degrees). Now, consider that the information spelled out by the letter-shaped bricks in the wall was the information that told the homunculus inside the engine when to open and close the shutter in the partition of the Szilard engine that preferentially allowed a particle to enter the cylinder (without allowing the particle to leave) and so push the piston to do useful work. No observation of the particle would be necessary because the only information that the first homunculus would need to know is when to open and close the shutter. So now a situation exists where the first homunculus can get the information to extract useful work out of the energy associated with the particle within the

engine by reading the information written on the inside of the wall, and that information can also simultaneously be read by a second homunculus on the outside of the wall (in its reverse image, i.e. phase shifted by 180 degrees) at the same time. In this situation the physical bricks that are in the shapes of letters are also the information by which the Szilard engine functions.

3. SIMULTANEITY

So now this can be considered as a very special case of a Szilard engine that is simultaneously both logically and thermodynamically reversible. It is thermodynamically reversible because the information necessary to convert the energy associated with the entropy of the particle inside the engine into useful work is completely available inside the Szilard engine. The information that exists inside the engine also exists outside the engine simultaneously, therefore any concern about the thermodynamic reversibility of a Szilard engine no longer holds in this very special circumstance because information cannot build up inside the engine since it is already simultaneously outside the engine, and so there is no need for energy input to erase it. It would simultaneously be logically reversible because the information about the useful work of the engine (i.e. the position of the piston) is physically preserved outside the engine in the position of the piston.

The information inside the Szilard engine is what provides for the thermodynamic reversibility of the engine, and the information outside the Szilard engine is what provides for the logical reversibility of the Szilard engine. In the special case of a Szilard engine that is physically constructed out of the bilaterally available information by which it functions, the simultaneity of the availability of the information to both sides of the engine provides the potential for such a reversible Szilard engine to function as a quantum gate in this special case.

The information about the timing of the opening and closing of the shutter of the Szilard engine partition would thus be simultaneously available to both a homunculus inside the engine and to a homunculus outside the engine. Essentially this puts a theoretical homunculus on both sides of the engine simultaneously. This information would not only allow for the transformation of the energy associated with the entropy of the particle inside the engine into useful work, but it would also allow a homunculus outside the engine to push back the piston at the proper time to push the particle back thru the shutter when the shutter would be open. Remember that the shutter is opened by the homunculus inside the Szilard engine as determined by the information about timing that is available to both homunculi simultaneously. Also remember that the information about the timing of the shutter is essentially the same information as that of the position and momentum of the particle inside the engine along with the information about the internal dimensions of the engine.

4. CONSISTENCY WITH PHYSICAL PRINCIPLES

The concept of a logically and thermodynamically reversible Szilard engine is consistent with the laws of physics. In particular the concept of the reversible Szilard engine does not violate the Second Law of Thermodynamics, or the Heisenberg Uncertainty Principle, or the No-Cloning Theorem.

The concepts of the “Maxwell’s demon” and the “Szilard engine” were originally presented strictly as illustrations to improve the understanding of entropy, and not originally presented as a means of violating the Second Law of Thermodynamics. Maxwell theorized his concept of what later was to be called “Maxwell’s demon” in order to show how the concept of entropy was a macroscopic concept in contrast to microscopic consideration of the particles involved, but he was not trying to show how to create free energy. Likewise, Szilard presented his concept of what later came to be referred to as the “Szilard engine” in order to show how information could convert the energy associated with entropy into useful work, but not as a means of creating free energy. The Second Law of Thermodynamics is predicated upon a closed system while the concept of the reversible Szilard engine is theorized to exist in an open system. An important point in understanding the reversible Szilard engine is that it is not designed to urn forever as a perpetual motion machine, rather it is a system that will run for a finite period of time, and in so doing can convert the energy associated with a moving particle into useful work, and the physicality of that useful work can be considered to have an information content that is consistent with the information by which the reversible Szilard engine functions. There is no need for concern about the long-term energy costs of working the shutter or sensing the particle in a reversible Szilard engine, because it is not intended to be a free energy machine.

The reversible Szilard engine is conceptualized to operate for a finite period of time, and the homunculus could theoretically be considered to run temporarily on its own temporary internal power supply, with its function to simply be that of opening and closing the shutter in accordance with the calculated timing. It is not a perpetual motion machine, rather, it is a theoretical machine designed to (for a finite period of time) use the information that it contains to convert the energy associated with the motion of the particle inside it into useful work, and the physicality of that work contains the information about the particle that is inside the engine. Thermodynamic reversibility is not the same thing as free energy, and a quantum gate is not the same thing as a perpetual motion machine.

The concept of a Szilard engine bounding wall containing information that is available to both sides of the wall simultaneously does not violate the Heisenberg Uncertainty Principle because the Heisenberg Uncertainty Principle deals with measurements, while the information in the information-containing bounding wall is known information that was built into the theoretical Szilard engine at its origin. In this theoretical case the homunculus of the Szilard engine only needs to know when to open and close the shutter and this timing information is available to the homunculus because it is written into the wall of the engine. While it is true that the timing information is essentially the same as the information about the position and momentum of the entropic particle inside the engine (along with the information about the internal geometry of the engine), the homunculus does not need to measure the particle to get this information. Therefore the Heisenberg Uncertainty Principle is not violated in this theoretical mechanism because there is no measurement.

The No-Cloning Theorem forbids the creation of separate but identical states, and it is not violated by the concept of the reversible Szilard engine because none of the three interacting qubits (the particle in the engine, the engine itself including the information by which it functions and the shutter, and the piston) are duplicated. The No-Cloning Theorem should not be considered to be violated simply because the information by which a reversible Szilard engine functions is available simultaneously to both sides of a wall of the engine. What would violate the No-Cloning Theorem would be if identical particles in identical states existed in two separate reversible Szilard engines at the same time, but this would be impossible. An information-containing bounding wall can contain the information to operate two Szilard engines that are linked by that wall, however, the information to operate one Szilard engine is specific to that engine, and also the information about the other Szilard engine on the opposite side of the information containing bounding wall would always be phase shifted by 180 degrees when available to the other linked Szilard engine. Therefore the no-cloning theorem is not violated by the theoretical mechanism of a reversible Szilard engine.

5. COHERENT LINKAGE

Two or more reversible Szilard engines could be theoretically linked by either their pistons and/or by their information-containing bounding walls. Since a quantum decision would be considered to have occurred if a shutter was closed, the two or more linked reversible Szilard engines would be considered to be in coherence if their shutters all remained open at the same time. A quantum decision (i.e. the closing of a shutter) in one of the linked Szilard engines could simultaneously effect similar decisions in other linked Szilard engines and thereby lead to decoherence of the system. Such a method of understanding quantum logic takes into account both the information and the physicality of the qubits involved.

If two reversible Szilard engines were theoretically linked by their pistons then the linked piston assembly could be considered to be freely moveable within the system as long as both shutters were open. In such a case of linked pistons, the movement of one piston would necessarily be dependent upon the movement of the other piston. Pistons that are linked by a linkage mechanism that is perpendicular to their directions of action could be considered to be in phase with each other, and the pistons would both simultaneously move in and out of their respective cylinders together. However, pistons that are linked by a linkage mechanism that is in line with their directions of action could be considered to be 180 degrees out of phase, and this would mean that when one piston would move out of its cylinder the other would be forced into its cylinder. If either of the shutters of two linked reversible Szilard engines were to be closed then this would theoretically "lock" both pistons of the system into a position, and this would in effect constitute a quantum decision that would affect the entire linked system of linked reversible Szilard engines.

If two reversible Szilard engines were theoretically linked by sharing an information-containing bounding wall, then the respective homunculi would know the timing of the action of each other's shutters and pistons and would be

able to simultaneously coordinate their shutter positions. The actions of the respective homunculi would not necessarily be interdependent, but they could be if coordinated by other information. A shift in the geometric orientation of the information-containing bounding wall shared by two linked reversible Szilard engines would theoretically constitute a phase shift in the shared information and thereby disrupt coherence between the two linked reversible Szilard engines.

There are unlimited possibilities for various potential configurations and concatenations of linked reversible Szilard engines. This can provide a basis for conceptualizing quantum logic "circuits" in a manner that not only takes into account the information involved, but also takes into account the physicality of that information, and thus the reversible Szilard engine might arguably be considered as a type of "universal quantum gate".

6. CONCLUSION

A Szilard engine uses information to convert the energy associated with entropy into useful work. If a Szilard engine is physically constructed out of the information by which it functions in such a way that the information is available to both sides of the engine at once, then that information essentially exists simultaneously on both sides of the mechanism and therefore cannot build up inside the engine. If the information necessary to convert the entropy of the finite number of particles inside the engine into useful work is sealed inside the engine with the homunculus then the thermodynamic reversibility of the Szilard engine is made possible. That information would ultimately be about the timing of when to open and close the shutter of the partition of the Szilard engine, but would essentially be the same as the information about the position and momentum of each particle in the engine along with the internal dimensions of the engine. A Szilard engine would be thought of as logically reversible if the piston can be pushed back into its original starting point. If a homunculus outside the Szilard engine could simultaneously know the information that the homunculus inside the Szilard engine knows, then the outside homunculus could move the piston while the shutter was open. Thus a reversible quantum decision can be made by the reversible symmetry break of a logically and thermodynamically reversible Szilard engine. This would essentially constitute the function of a quantum gate operating on qubits of information concerning an entropic particle's position and momentum (i.e. shutter timing), and the internal and external dimensions of the theoretical mechanism (which can be considered as a constant).

The concept of a reversible Szilard engine functioning as a quantum gate provides for a more complete conceptualization of both the information and the physicality the qubits that interact in a quantum gate. The interacting qubits consist of the particle inside the reversible Szilard engine, the reversible Szilard engine itself (which includes the information by which it functions and the shutter), and the piston. Phonons can be conceptualized as the movement of the piston of the reversible Szilard engine, which is theoretically a quantized entity with a reciprocating distance, an energy (derived from the particle in the engine), and a direction. Coherence can be conceptualized as consisting of two aspects which are an information-containing bounding wall shared between the two reversible Szilard engines, and a linkage of the pistons of two reversible Szilard engines that have their shutters open at the same time. Coherence thus conceptualized can be broken by either a phase change in the shared information-containing bounding wall, or by closure of one of the shutters in the system of piston-linked reversible Szilard engines. Consideration of the reversible Szilard engine (RZE) as a type of "universal quantum gate" will advance efforts to construct a practical quantum computer because it provides for the conceptualization of the physicality of the interaction of the information involved in quantum logic.

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