cGh-lim(its) of processing bits

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Regardless of physical status of information, its processing is definitely a material process. H. J. Bremermann was the first who, back in 1962 asked if physical laws limit the rate of any data processing. His positive answer of 1962 has to be corrected to make it compatible with General Relativity. As a result, *Bremermann's limit*, proportional to mass M of processor, $Mc^2/h = \sim (M/\text{gram})10^{47}$ bits per second, should be replaced by an absolute limit $(c^5/Gh)^{1/2} = \sim 10^{43}$ bits per second, where universal constants c, G, and h are the speed of light, the gravitational constant, and Planck's constant. The question of ultimate status of information is intertwined with the problem of Quantum Gravity.

Do physical laws limit computational rate, or bit rate, of any data processor? The first positive answer was suggested by H. J. Bremermann back in 1962 as the so called Bremermann's limit $Mc^2/h = \sim (M/\text{gram})10^{47}$ bits per second, where M is the mass of processor, c is the speed of light, and h is Planck's constant.[1] This limit resulted in the maximum processing rate for 'ultimate (1kg) laptop', $\sim 10^{50}$ bits per second. [2]

Bremermann himself pointed out that the maximum bit rate of a processor with a mass equal to the mass of Earth (10^{75} bps) is small compare to numbers of all move sequences in chess or patterns in a black and white mosaic of 100×100 cells. However even if bit rates 10^{47} and 10^{75} are not high enough for some computational problems, the inverse values, that is durations of one operation – 10^{-47} and 10^{-75} sec, are unreasonably small for the theoretical physics taking into account the problem of quantum gravity. The theory of quantum gravity has not been created up to now, but well known are certain characteristic values of physical parameters, beyond which the current physical theories are not applicable. These are so-called ***Planck values***, constructed from three universal constants c, G, h that are engaged in fundamental physical theories: the speed of light c (relativity theory), gravitational constant G (theory of

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gravity), and Planck's constant h (quantum mechanics). [3] In particular, Planck time Δt_{cGh} = $(hG/c^5)^{1/2}$= 10^{-43} sec is well above the indicated Bremermann durations of one operation, although such an operation has to be realized in some physical processes.

To deal with this contradiction let's revisit Bremermann's way to his limit. Although he called his limit arising from quantum theory, in fact he employed the theory of relativity as well, since he used both quantum relation $\Delta E \Delta t > h$ and relativistic one $E = Mc^2$. However he ignored the size of processor, and hence implicitly assumed the infinite speed of signal propagation within processor, which contradicts to relativity.

To get the minimal operation time Δt in a processor with mass M and linear size L, we should combine quantum limitation $\Delta t > h/\Delta E$, relativistic limitation of available energy $\Delta E < Mc^2$, and the fact that the speed of signal within processor does not exceed the speed of light $\Delta t > L/c$.

Hence, $\Delta t > \max\,[h/Mc^2, L/c]$.

It would lead to Bremermann's limit $\Delta t_B = h / Mc^2$, if one could choose L to be arbitrarily small: $L < h/Mc$. However, one is not absolutely free to choose values L and M because of gravity, and here comes the third universal - gravitational - constant G. To prevent the processor from turning into a "black hole" and disappearing beyond the event horizon the condition $L > GM/c^2$ must be met. So, we get to the minimal time of operation

$\Delta t_{min} = (Gh/c^5)^{1/2} = \sim 10^{-43}$ sec, that is Planck time Δt_{cGh}.

Hence the *absolute* - independent on the processor's mass - *maximum bit rate* is

$(\Delta t_{cGh})^{-1} = (c^5/Gh)^{1/2} = \sim 10^{43}$ bits per second.

The necessity to correct Bremermann's maximum rate (to comply with General Relativity) does not diminish the importance of his question whether fundamental laws of physics limit processing rate. The significance of such a limit was emphasized by Ross Ashby in the 60s as a borderline between possible and impossible for humankind. [4] The quantum limits of General Relativity and the real challenge of quantum gravity were discovered in 1935 by Matvei Bronstein, who had no much time to develop *cGh*-physics: in his 30 he was arrested and executed during the Great Terror. [5]

Regardless of ontological status of information, its processing is definitely a physical process. Quantum thermodynamics of black holes (by J Bekenstein and S Hawking) was the first connection of information, quantum and gravity at the a borderline between visible and invisible. The *cGh*-limit of processing information is a reason to believe that the question of ultimate physical status of information is to be answered together with the question of Quantum Gravity.

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