Entanglement of spacetime bits as the driver of entropy increase from more precise timekeeping.

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Current research is noted addressing the observed increase in entropy from more accurate or increased precision timekeeping experiments. Entanglement of fundamental spacetime bits in a fully meshed system (single observation) is proposed as the origin of entropy increase with the rate of increase in both following a similar graphical pattern. The short essay is speculative and does not involve advanced calculations.

> *Time, time, time*
> *See what's become of me*
> *While I looked around for my possibilities…*
> *Seasons change with the scenery*
> *Weavin' time in a tapestry*
> *Won't you stop and remember me?*
> *-- Hazy Shade of Winter, Paul Simon*

> *I think it's a very, very interesting question whether the cosmological growth of space is connected to the growth of some kind of complexity. And whether the cosmic clock, the evolution of the universe, is connected with the evolution of complexity. There, I don't know the answer.*
> *-- Dr. Leonard Susskind, Quanta Magazine interview [1]*

> *Bekenstein argued that the vast majority of the states included in such a calculation are physically unattainable, and that the entropy of a system with mass M and linear size R is bounded by $S \leq 2\pi RM$. Since a system with $GM > R/2$ undergoes gravitational collapse to a black hole, this … represents an upper bound on the entropy of any system in spacetime.*
> *-- Cao, C., Carroll, S. M., & Michalakis, S. Space from Hilbert space: recovering geometry from bulk entanglement [2]*

> *[T]he emergence of spacetime in the gravity picture is intimately related to the quantum entanglement of degrees of freedom in the corresponding conventional quantum system. … It is fascinating that the intrinsically quantum phenomenon of entanglement appears to be crucial for the emergence of classical spacetime geometry.*
> *-- Mark Van Raamsdonk, General Relativity and Gravitation [3]*

> *If I close my eyes forever*
> *Will it all remain unchanged?*
> *If I close my eyes forever*
> *Will it all remain the same?*
> *-- Close My Eyes Forever, Lita Ford and Ozzy Osbourne Ozzy*

In the January 1, 2022 edition of New Scientist, Miriam Frankel interviewed Emily Adlam from the Rotman Institute of Philosophy at Western University in Canada for her article on "what the thermodynamics of clocks tell us about the mysteries of time." Adlam's responses, specific to the relationship between the precision of timekeeping and entropy, include:

> [T]here are limits on how accurately we can tell the time, due to the involvement of energy's messy cousin, entropy…. There is still a question of why we only ever experience time moving forwards. What is needed… is a direct link between thermodynamics and practical timekeeping – something

> explaining why all clocks run in the same direction as the entropy increase of the universe. … This was the first result to explain why clocks move forwards in time, because as they measure time, they increase entropy, an irreversible process. This research gives a very nice explicit link between the thermodynamic arrow of time and perceptual time…. Perhaps quantum measurements, like clocks, create rising entropy and hence an emergent arrow of time. [4]

Perhaps the answer to the question posed above, is that increased precision in timekeeping involves a greater aggregate number of entangled bits of spacetime. Figure 1 is not, by any means, to scale, but is used as an analogy where the precision increase in timekeeping is analogous to an increase in fundamental spacetime quantum entanglement where a given span of time recorded, of say nine seconds recorded at one second intervals, will require much less entangled "bits" of spacetime than if that same span was tracked down to nano-second precision. The analogy being that the clockface space "swept" or traversed by a physical clock's second hand is analogous to the number of full-mesh entangled spacetime bits needed for the precision recording of time. An assumption here being that all the bits need to be entangled for a given measurement or observation.

In the Figure 1 example, we can see how the image on the left involves 11 entangled spacetime bits thus 55 links (i.e., ((n (n-1))/ 2) for a fully meshed “system” for the given time observation versus the image on the right of 43 bits and thus 903 links. Figure 2 shows how the rate of fully meshed entangled bits increases at a rate similar to that of the increase in entropy over time in the Universe that also closely resembles the rate of the proposed Dark Energy accelerating expansion of the Universe. Also, famous research known as EP=EPR implies entanglement as the origin of space itself.

Again, in an attempt to answer the challenges posed in the New Scientist article, if we reverse the logic, then perhaps the proposed increase in spacetime entanglement seen in Figure 1, from more precision timekeeping, and thus possibly for any observer or observation, leads to the forward arrow in time. The assumptions also include spacetime as a lattice with fundamental bits likely akin to Planck length units. Calculations with these known quantities and thermodynamic limits as demonstrated in the Bekenstein Bound and the Second Law of Thermodynamics can give more precise results in terms of the number of required bits, but this essay is written as general speculation for additional research and consideration.

Fig 1. More precision in measuring a span of time involves more bits of entangled spacetime.

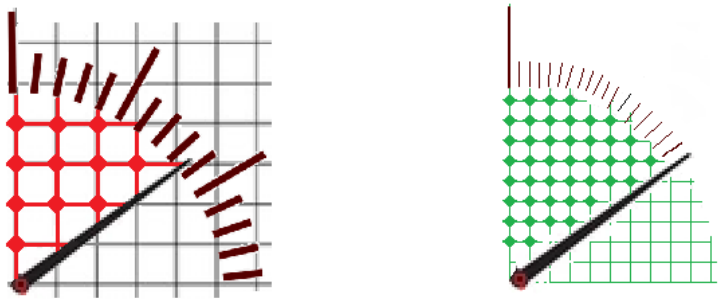
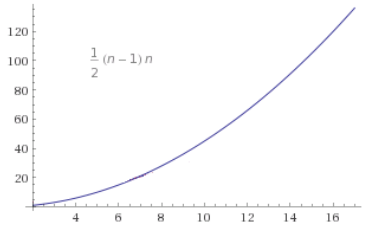
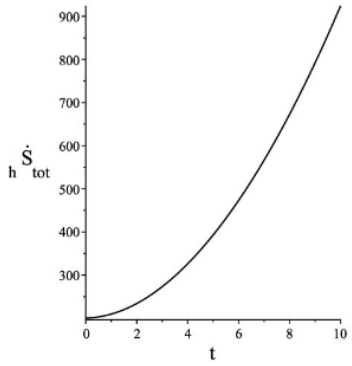


Fig 2. Side-by-side comparison of three potentially associated graphs:

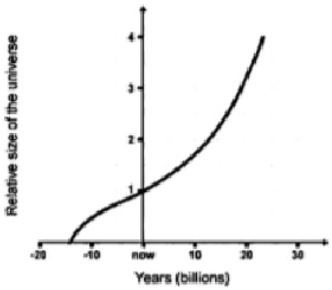
Node versus Link count - full-meshed (entangled) network



Total entropy versus time evolution [5]



Universe size versus Time - Dark Energy driven accelerated expansion of the Universe [6]



References

[1] Susskind, L. (2018). Three lectures on complexity and black holes. *arXiv preprint arXiv*:1810.11563.

[2] Cao, C., Carroll, S. M., & Michalakis, S. (2017). Space from Hilbert space: recovering geometry from bulk entanglement. *Physical Review D*, 95(2), 024031.

[3] Van Raamsdonk, M. (2010). Building up spacetime with quantum entanglement. *General Relativity and Gravitation,* 42(10), 2323-2329.

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