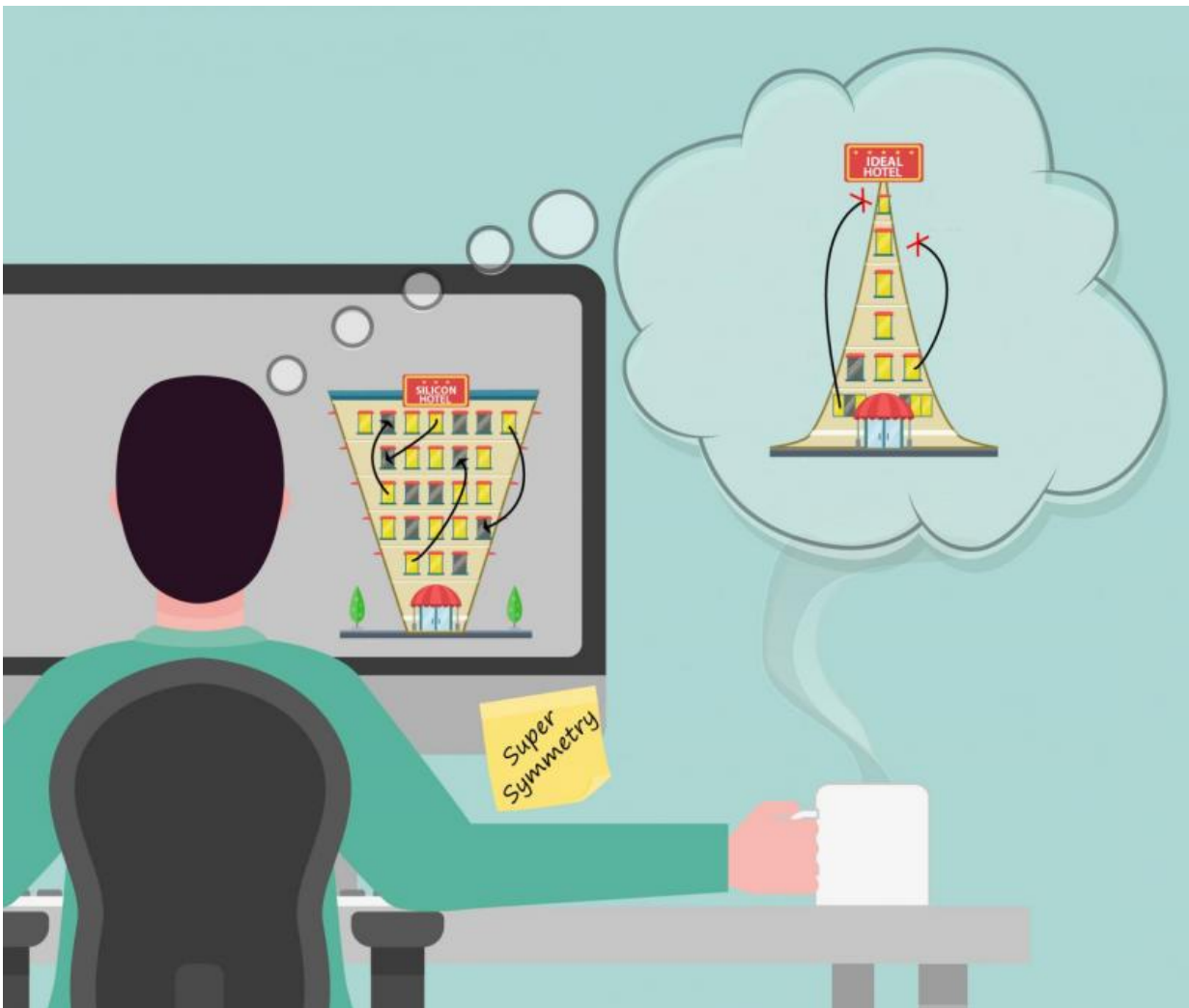


# Can anti-aging research help future memory devices?

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Analogy to compare the properties of different materials for data storage. The energy level of electrons can be represented as floors of a hotel occupied by electrons. In the case of the “Silicon Hotel”, shown on the computer screen, there

are several rooms available in each floor, meaning that electrons rich with data on the top floors can easily exchange their energy and data with electron on the lower floors. The more of these interactions the material has, the shorter the lifespan for data storage. Instead, the “Ideal Hotel” does not have any rooms available upstairs, electrons cannot interact with each other, neither swap rooms. Eventually, there would be some exchanges, but it would take a very long time. A material with this type of energy levels would store information for much longer than the current silicon-based devices. Credit: Institute for Basic Science

Nothing is forever, but is it possible to slow down inescapable decay? An inquiry into the delay of deterioration of quantum memory devices and formation of black holes explained with intuitive analogies from everyday life

Inevitably, large stars at the end of their life collapse under the gigantic force of gravity, turning into black holes. We could cunningly ask if there is a way to delay this process; postpone the death of the star. While investigating "anti-aging therapy" of large stars, researchers at the Center for the Theoretical Physics of the Universe, within the Institute for Basic Science (IBS) conceptualized an ideal material that could store data for an exceptionally longer time than current short-lived devices, bringing new hints for future [quantum](#) memory technologies.

Archaeologists have been able to discover, and often decipher, messages left by ancient civilizations in clay tablet, stone or paper. These specimens made it into the 21st century, but will our digital messages survive in pristine condition for thousands of years? The production of new digital information is bigger than ever before, but silicon-based devices come with an expiration date: it is around 3 to 5 years for hard disks and 5 to 10 years for flash storage devices, CDs and DVDs. Sadly, all our priceless memories stored as digital photos, videos and digitalized documents are not going to be available to our descendants, unless of

course we carefully copy them to new devices from time to time. Overcoming this limitation is one of the biggest challenges faced by scientists today. "We all die, but we want to slow down the aging process, so that we can live longer, much longer than now. The same goes for our digital data, we want to prolong their existence," says Soo-Jong Rey, director of the Field, Gravity, and Strings Group at the Center for the Theoretical Physics of the Universe.

Going quantum is the best way to harness the many facets of the nanoscale world. It lets us exploit the quantum property of "quantum entanglement" whereby coherent structures can be formed at these small scales. The fundamental quantum principle was raised by Rolf Landauer back in 1961. He discovered that heat and information are intimately connected. Processing data generates heat and, for this reason, information deteriorates and cannot be stored forever. Now with digital miniaturization, we are bringing technology to its quantum limits. Information is stored in smaller and smaller quantum scale devices, against its natural tendency to spread out, and therefore generating even more heat.

Needless to say, decline and decay are part of life, as it all boils down to [energy](#) transfer. It is the same phenomenon that causes a hot coffee to reach room temperature when in contact with a cool mug and air. Energy is transferred from the coffee to the mug and eventually to the air. Energy tends to dissipate, unless it is shielded and confined. This exchange process that reduces the temperature of coffee is ultimately connected to a quantum information process that physicists call "scrambling" at the ultimate quantum scale. As the word suggests, scrambling involves the mixing of energy and information where the originals cannot be retrieved, in the same way that the yolk and white are not recognizable in a scrambled egg.

In order to keep the coffee warm for longer, it would be necessary to

shield it from any other cooler materials or substances. In the case of memory devices, to keep the device working for longer, [electrons](#) or atoms bearing energy or information of quantum units should not interact with other electrons and atoms and need to be isolated as much as possible. The confinement is created by other atoms that form a barrier. A long time ago, Phil Anderson proved that this atom-built barrier perfectly works if our world was one-dimensional, such as a line. Imagine having atoms in a line and putting an obstacle in the middle to keep them far apart. However, if they move in a two-dimensional flat land or in a three-dimensional material, this issue is notoriously complicated. Although the semiconductor industry is specialized in controlling these barriers, atoms can always find paths to move around or jump and reach their neighbors.

To complicate the issue even further, it was discovered that electrons move together as clusters, called strongly correlated systems or many-body systems. So while scientists want to isolate single atoms and electrons and prevent them from interacting with each other, holding the reins of a cluster of them is even more challenging.

In order to find an idealized system that is localized and correlated at the same time, the IBS research team relied on an exotic concept called supersymmetry. "In supersymmetry, each particle has a partner. For example, each electron pairs with a selectron of the same energy and mass. Because of these pairings, the system can be solved with pen and paper, without the need for a computer simulation, no matter how many particles you have," says Rey.

Using the mathematical principles of supersymmetry, the scientists conceptualized an ideal material with the right structural organization that could store quantum data for an exceptionally long time, "exponentially longer than the current [memory devices](#)."

The material they envision has a special architecture of energy levels for its electrons. Energy levels can be imagined as the floors in a hotel. However, the shape of the hotel looks different depending on the type of atom. The more energy the electron has, the higher floor it occupies. So electrons involved in data storage would occupy the top floors. Using this analogy, the hotel for silicon has a shape similar to an upside-down pyramid with rooms available in each floor. Electrons with data on the top floor can easily exchange their energy or data with electron on the lower floors. In this way, they swap rooms with other electrons by transferring energy or data. Room swap after room swap, scrambling will occur.

The hotel proposed by Rey's research team, instead, tapers quickly as it climbs taller. In this hotel, most of the electrons are on the first floor because very few rooms are available in the higher floors. Since there are not any rooms available upstairs, electrons cannot interact with each other, and they cannot swap rooms. In this way, data from the electrons in the top floors are not lost as time passes. Eventually, the scrambling process will happen, but it would take an exponential time.

"The second law of thermodynamics states that the entropy cannot decrease, but it does not mention how much time it takes for an ordered state to become chaotic. So the name of the game is longevity; to prolong it as much as possible," clarifies Rey. "Eventually, of course, the hotel will collapse, entropy is the ultimate winner, it is unavoidable, but we want to make sure that such victory comes only after a very long time."

Although a material with such [energy levels](#) does not exist yet, this new understanding can guide material scientists and memory device engineers on how to develop superior memory storage devices that fit to this concept and that could replace silicon.

Going back to the "large stars' anti-aging therapy", in the same way as it

is theoretically possible to design a material for longer digital storage, scientists are wondering if it is possible to point at precise criterion to delay the decay of large stars. In other words, could they delay the formation of [black holes](#)? Future research will tell.

The study was published in the *Journal of High Energy Physics*.

**More information:** Pramod Padmanabhan et al. Supersymmetric many-body systems from partial symmetries—integrability, localization and scrambling, *Journal of High Energy Physics* (2017). [DOI: 10.1007/JHEP05\(2017\)136](#)

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