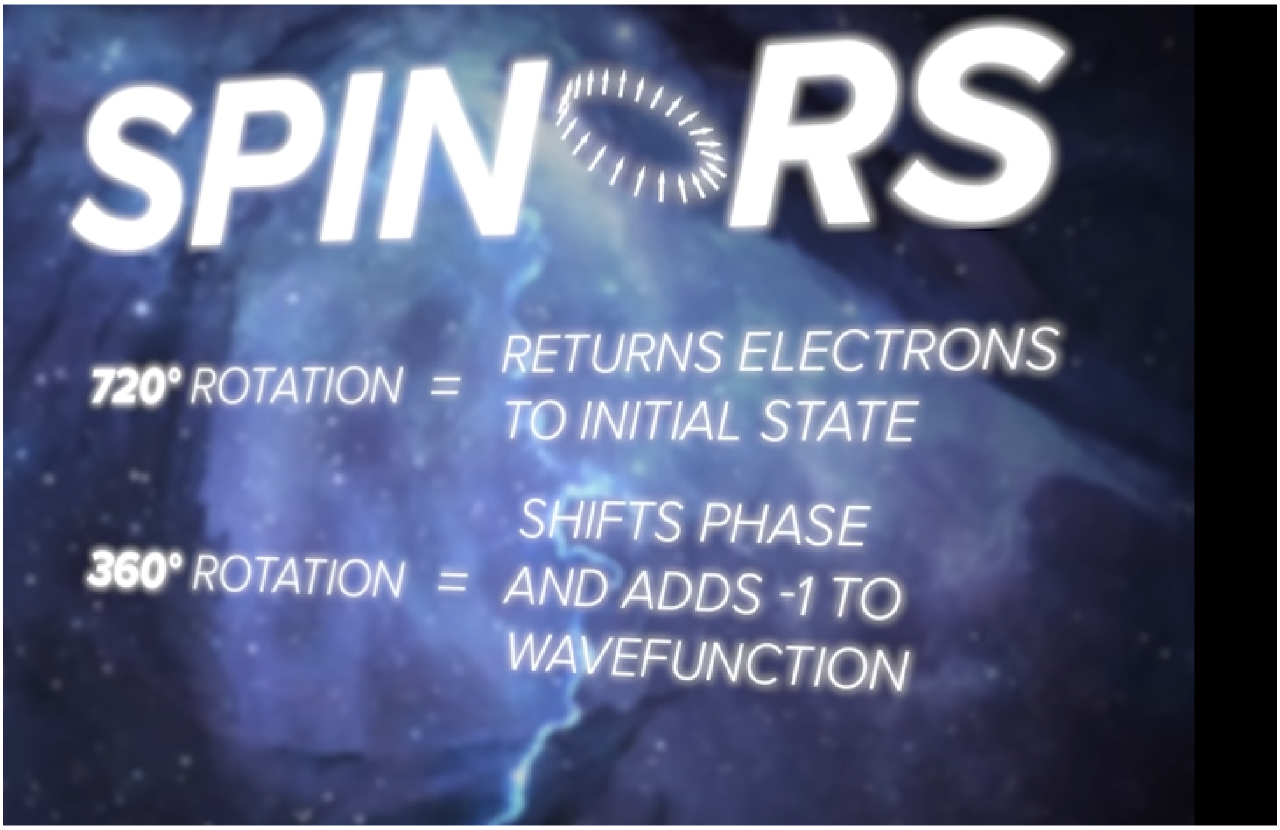
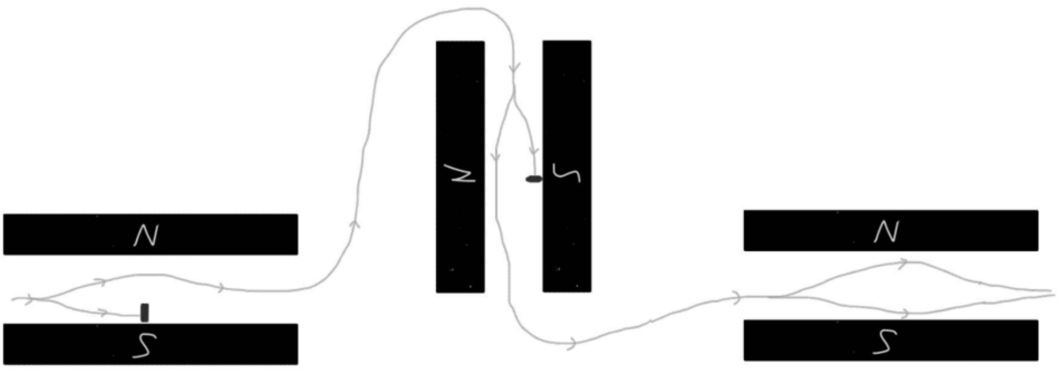
Random info

- Princip lokalnosti = nikakav uticaj ne može putovatu brže od brzine svjetlosti.
- Bel je pokazao da je bilo koja lokalna teorija skrivenih varijabli nekompatibilna sa kvantnom mehanikom.
- Nase opcije su da je KM nekompletna i pogresna, ili da teorija skrivenih vaarijabli ne pije vode i nista nas ne moze spasiti od nelokalnosti.
- According to classical mechanics the angle of two detectors should have a linear relationship to what percentage of time the two particles have spins in oposite direction $\rightarrow$ 75% of the time
    - according to QM this relationship is a sine wave $\rightarrow$ 85% of the time
        - measurements are always as the QM predicts
- SPINORS
    - belt analogy
    - 720° rotation returning to original configuration
    - 360° rotation $\iff$ swaping places
    - 

So the bottom line is that the measurement of the spin in the x-direction "produces" spin down states in the z-direction even though we did filter all such states out in the first step. In other words, the measurement of spin in the x-direction erases all information we previously collected about spin in the z-direction.



- In quantum mechanics, a singlet state usually refers to a system in which all electrons are paired. The term 'singlet' originally meant a linked set of particles whose net angular momentum is zero, that is, whose overall spin quantum number s = 0 s=0. As a result, there is only one spectral line of a singlet state. In contrast, a doublet state contains one unpaired electron and shows splitting of spectral lines into a doublet; and a triplet state has two unpaired electrons and shows threefold splitting of spectral lines.
- It turns out it’s not possible to build any detector that can measure a particle’s spin along multiple axes at the same time. Quantum theory asserts that this property of spin detectors is actually a property of spin itself: If an electron has a definite spin along one axis, its spin along any other axis is undefined.
- When both teams measure along the same axis, they obtain opposite results 100% of the time. But is this evidence of nonlocality? Not necessarily.
- Bell proved that you could rule out local hidden variable theories, and indeed rule out locality altogether, by measuring entangled particles’ spins along different axes.
- cool link about bells ineq
- Thus the labs will obtain opposite results when measuring along different axes at least 33% of the time; equivalently, they will obtain the same result at most 67% of the time. This result — an upper bound on the correlations allowed by local hidden variable theories — is the inequality at the heart of Bell’s theorem.

- In a Bell test, entangled photons A and B are separated and sent to far-apart optical modulators — devices that either block photons or let them through to detectors, depending on whether the modulators are aligned with or against the photons' polarization directions. Bell's inequality puts an upper limit on how often, in a local-realistic universe, photons A and B will both pass through their modulators and be detected

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- Certainly. The connection between EPR and ER is typically explored using the mathematical framework of quantum field theory and general relativity.

In quantum field theory, the entanglement between two particles is described by a concept called entanglement entropy, which is a measure of the amount of entanglement between two regions of space. This quantity can be calculated using the reduced density matrix of the entangled particles, and it is related to the correlations between the measurements of the particles.

On the other hand, in general relativity, the curvature of space-time is described by the Einstein tensor, which is a mathematical object that encodes the curvature of space-time due to the presence of matter and energy. The presence of a black hole is described by the Schwarzschild metric, which is a solution to Einstein's equations of general relativity that describes the curvature of space-time around a non-rotating black hole.

The connection between EPR and ER comes from the fact that the entanglement entropy of two particles can be related to the area of a wormhole connecting them. This connection was first proposed in a 2013 paper by Juan Maldacena and Leonard Susskind, and it is based on the holographic principle in string theory.

According to the holographic principle, the information contained in a region of space can be encoded on the boundary of that region, much like a hologram encodes a three-dimensional image on a two-dimensional surface. In the case of a black hole, the holographic principle suggests that the information that falls into the black hole can be encoded on the event horizon, which is the boundary of the region of space from which nothing can escape.

The key insight of the ER=EPR conjecture is that the entanglement between two particles can be thought of as a connection between two different regions of space, just like a wormhole. Specifically, the entanglement entropy between the two particles is proportional to the area of the wormhole that connects them.

This connection has been explored in various contexts, such as in the study of the information paradox in black holes and the relationship between entanglement and the geometry of space-time. However, it should be noted that the ER=EPR conjecture is still a conjecture and it is an active area of research to understand its implications and whether it holds true in various situations.

- In quantum mechanics, the concept of entanglement arises when two or more particles become correlated in a way that cannot be described by classical physics. When two particles are entangled, measuring one particle's state will instantaneously affect the state of the other particle, no matter how far apart they are.

One way to quantify entanglement between two quantum systems is through the concept of entanglement entropy. Entanglement entropy is a measure of the amount of entanglement between two subsystems of a larger quantum system. Specifically, it quantifies how much information is shared between the two subsystems and how much is unique to each subsystem.

The entanglement entropy is calculated by taking the reduced density matrix of one of the subsystems, which is obtained by tracing out the degrees of freedom of the other subsystem. The entanglement entropy is then given by the von Neumann entropy of the reduced density matrix.

- The holographic principle is a concept in theoretical physics that relates the properties of a quantum field theory in a certain number of dimensions to the properties of a gravitational theory in one higher dimension. In essence, it suggests that the information contained in a volume of space can be encoded on its boundary.

The holographic principle was first proposed in 1995 by Gerard 't Hooft, and was later developed further by Leonard Susskind and Juan Maldacena. The idea is based on the observation that the number of degrees of freedom required to describe a physical system is proportional to its volume or area. The holographic principle takes this observation further by suggesting that the maximum number of degrees of freedom that can be contained in a region of space is proportional to its surface area rather than its volume.

In particular, the holographic principle suggests that a gravitational theory in n+1 dimensions can be described by a quantum field theory in n dimensions. This is known as the AdS/CFT correspondence, which stands for Anti-de Sitter/Conformal Field Theory correspondence. According to this correspondence, a gravitational theory in a curved spacetime known as Anti-de Sitter (AdS) space is equivalent to a quantum field theory living on the boundary of that space.

This correspondence has many applications, particularly in the study of black holes and the relationship between quantum mechanics and gravity. In particular, it has led to the realization that the entropy of a black hole, which is proportional to its surface area, can be accounted for by the degrees of freedom on the boundary of the AdS space. This has provided new insights into the nature of black holes and the fundamental nature of space and time.

The holographic principle has also been used to explore other areas of physics, such as condensed matter physics, where it has been used to study the properties of strongly correlated systems.

Overall, the holographic principle is a fascinating concept that has profound implications for our understanding of the nature of space, time, and the relationship between quantum mechanics and gravity.

- Quantum entanglement is a fundamental concept in quantum mechanics that refers to the correlation between two or more particles that have interacted in the past. In quantum field theory, the concept of entanglement can be extended to fields, which are described by quantum fields.

In quantum field theory, entanglement between two regions of space can be defined in terms of the reduced density matrix of one of the regions. The reduced density matrix is obtained by tracing over the degrees of freedom of the other region. If the reduced density matrix of one region is not a pure state, but a mixed state, then the two regions are said to be entangled.

The entanglement between two regions of space can be quantified by a measure called the entanglement entropy, which is defined as the von Neumann entropy of the reduced density matrix. The entanglement entropy is a measure of the amount of entanglement between the two regions of space, and it is proportional to the area of the boundary between the two regions.

In quantum field theory, entanglement plays an important role in the study of many phenomena, including the behavior of black holes and the emergence of spacetime from entanglement. Entanglement also plays a central role in the study of quantum information and quantum computing, where it is used to implement quantum algorithms and protocols such as quantum teleportation and quantum cryptography.

- Certainly! In quantum mechanics, the state of a system is described by a wave function, which is a mathematical function that encodes all the information about the system's properties that can be measured. The wave function gives the probability amplitude for the system to be in any particular state.

When two or more quantum systems are entangled, their wave functions are no longer independent of each other, and the state of one system cannot be described without reference to the state of the other system. In this case, the joint state of the two systems is described by a wave function that describes the entire system.

However, in many situations, we are interested only in the properties of one of the entangled systems. For example, we might want to know the state of a single particle in a larger system that is entangled with other particles. In this case, we can define the reduced density matrix of the particle, which gives the probability distribution of the particle's states, averaged over all the possible states of the other entangled particles.

The reduced density matrix is obtained by tracing over the wave function of the other particles, which effectively removes the degrees of freedom of the other particles from consideration. The result is a density matrix that describes the state of the single particle.

The reduced density matrix is a powerful tool in quantum mechanics and is used to calculate the properties of entangled systems, such as the entanglement entropy that I mentioned earlier. The entanglement entropy is related to the amount of information that is shared between the entangled systems, and it can provide insight into the nature of quantum entanglement and its role in the behavior of quantum systems.

- In the context of quantum mechanics, a "pointer" is a quantum system that is used to measure or indicate the state of another quantum system. The term "pointer" is used because the quantum system being measured is analogous to the hand of a clock, which points to the current time.

To understand how pointers work in quantum mechanics, consider a simple example of a quantum system with two possible states, which we'll call |0> and |1>. Suppose we have a second quantum system, called a "probe," that is coupled to the first system in such a way that its state depends on the state of the first system. Specifically, suppose that if the first system is in the state |0>, the probe is left unchanged, but if the first system is in the state |1>, the probe is shifted to a new state |a>.

Now suppose we want to measure the state of the first system. One way to do this is to prepare a third quantum system, called a "pointer," in a state that is coupled to the probe in such a way that the pointer is shifted to a new state |b> if the probe is in the state |a>, but is left unchanged if the probe is in the state |0>. Thus, the final state of the pointer depends on the state of the first system.

This process of using a pointer to measure the state of a quantum system is analogous to the process of reading a clock to determine the current time. In both cases, a second system is used to indicate the state of the first system, and the state of the second system is interpreted as a measurement of the state of the first system.

In practice, pointers can be implemented using a variety of different physical systems, such as atoms, photons, or superconducting circuits. The details of how a pointer is implemented depend on the specific context and the goals of the measurement. However, the basic idea of using a quantum system to indicate the state of another quantum system remains the same.

- no matter what state you write down, there is always some direction of space such as, if the electron is in this state:

$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

then the spin along that direction is up. Any vector that you write down is an eigenvector of some $\sigma \cdot n$

- lecture number 4
  - ako imas dva elektrona, cije je stanje opisano sa

$$|u, d > + |d, u >$$

prateci logiku pojedinacnog elektrona, trebalo bi da postoji neki pravac u kojem je spin elektrona sigurno up, tacnije $\sigma \cdot n \neq 0$
medjutim, ako potrazis srednju vrijednost, ocekivanu vrijednost sigma operatora u takvom stanju dobijes da je za sve tri komponente rezultat nula, pa je i projekcija na neki n pravac jednaka nuli, tako da za arbitrarni pravac po kojem bi mjerila spin, imas 50% sansu da je up i 50% da je down

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- Leonard Susskind's lectures on quantum entanglement cover a wide range of topics related to the phenomenon of entanglement, including:

  What is entanglement: Entanglement is a property of quantum mechanics in which two or more particles become correlated in such a way that their behavior cannot be understood independently of one another. This means that the state of one particle can instantaneously affect the state of the other particle, even if they are separated by a large distance.

Types of entanglement: There are two main types of entanglement - bipartite entanglement, which involves two particles, and multipartite entanglement, which involves more than two particles.

Applications of entanglement: Entanglement has a number of practical applications in areas such as quantum computing and cryptography, as well as theoretical implications for our understanding of the nature of physical reality.

Entanglement and non-locality: Entanglement is often described as a non-local phenomenon, meaning that the correlations between entangled particles violate the principle of locality, which states that the behavior of a particle should be determined only by its immediate surroundings.

Bell's theorem: Bell's theorem is a fundamental result in quantum mechanics that shows that the predictions of quantum mechanics cannot be reproduced by any theory that relies on local hidden variables. This implies that any theory that reproduces the correlations predicted by quantum mechanics must violate the principle of locality.

Entanglement and black holes: Susskind also discusses the relationship between entanglement and black holes, and how the phenomenon of entanglement is related to the information paradox of black holes.

Overall, Susskind's lectures provide a comprehensive and accessible introduction to the concept of entanglement and its implications for our understanding of quantum mechanics and the nature of physical reality.

- Sure, here is a summary of Susskind's lectures on quantum entanglement with more mathematical details:

  Entanglement is a phenomenon where two or more particles are described by a single quantum state, and the behavior of one particle cannot be understood independently of the others. The most common measure of entanglement is the von Neumann entropy, which quantifies the amount of entanglement between two subsystems of a larger quantum system.

  Bipartite entanglement can be quantified using the Schmidt decomposition, which expresses a state of a two-particle system as a linear combination of orthonormal states that are entangled. This decomposition can also be used to determine the entanglement entropy, which measures the degree of entanglement between the two subsystems.

  Multipartite entanglement is more complex and can be described using different measures, such as the geometric measure of entanglement or the convex-roof extension of the entanglement entropy.

  Entanglement has practical applications in quantum computing and cryptography, where it is used for tasks such as teleportation, superdense coding, and quantum key distribution.

  Bell's theorem provides a way to test whether the correlations between two entangled particles violate the principle of locality. The violation of Bell's inequalities implies the presence of non-local correlations that cannot be explained by any local hidden variable theory.

  Black holes are also related to entanglement, as they can be thought of as the ultimate entangled systems. The entropy of a black hole is proportional to its surface area, which suggests a deep connection between gravity and entanglement.

Susskind's lectures provide a rigorous and in-depth exploration of the mathematical foundations of entanglement, as well as its broader implications for our understanding of quantum mechanics and the universe as a whole.

- Sure, here are some of the key formulas related to the topics discussed in Susskind's lectures on quantum entanglement:

  The von Neumann entropy of a density matrix ρ describing a bipartite system with subsystems A and B is given by:

  $S(\rho_A) = -Tr(\rho_A \log(\rho_A))$

where $\rho_A = Tr_B(\rho)$ is the reduced density matrix of subsystem A.

```
The Schmidt decomposition expresses a state of a two-particle system as:

|Ψ⟩ = ∑_i λ_i |α_i⟩⊗|β_i⟩
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where λ_i are the Schmidt coefficients and $\{|\alpha_i\rangle\}$ and $\{|\beta_i\rangle\}$ are orthonormal bases for subsystems A and B, respectively.

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The entanglement entropy for a bipartite system is given by:

S(ρ_A) = -Tr(ρ_A log(ρ_A))
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where ρ_A is the reduced density matrix of subsystem A.

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The geometric measure of entanglement for a multipartite system is given by:

E_G = min_ρ_S (-log_2(F(ρ_S, |ψ⟩)))
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where $F(\rho_S, |\psi\rangle)$ is the fidelity between the reduced density matrix ρ_S of subsystem S and the pure state $|\psi\rangle$.

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Bell's inequality for a two-particle system with measurement settings a and
b and measurement outcomes ±1 is given by:

|⟨A(a)B(b)⟩ - ⟨A(a)B(b')⟩| + |⟨A(a')B(b)⟩ + ⟨A(a')B(b')⟩| ≤ 2
```

where A(a) and B(b) are the observables measured on particles A and B, respectively, with settings a and b.

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The entropy of a black hole with area A and gravitational constant G is
given by:

S = k_B A/(4ℏG)
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where k_B is the Boltzmann constant and $\hbar$ is the reduced Planck constant.

These formulas provide a mathematical framework for understanding the concepts and ideas presented in Susskind's lectures on quantum entanglement.

- Bell's theorem is a mathematical result that concerns the behavior of entangled particles. Entanglement refers to the fact that the properties of two or more particles can become correlated in a way that cannot be explained by classical physics.

Consider two particles, A and B, that are entangled such that their properties are correlated. Let's say that we measure the spin of each particle along a particular axis, denoted by a and b respectively. We can denote the possible outcomes of these measurements as +1 or -1, corresponding to the particle having spin up or spin down along that axis.

The predictions of classical physics, which obey locality, would suggest that the measurements of A and B are independent of each other, and any correlations between the measurements must be due to some hidden variables that are shared by the particles.

However, Bell's theorem shows that this is not always the case. Bell's inequality is a mathematical expression that holds true for any theory that obeys locality. It relates the expectation value of the product of the spin measurements to the individual expectation values:

$|E(ab)| \leq E(a) + E(b)$

where $E(ab)$ is the expectation value of the product of the spin measurements, and $E(a)$ and $E(b)$ are the individual expectation values of the spin measurements.

Quantum mechanics predicts that in some cases, the measurements of A and B will violate Bell's inequality, meaning that $|E(ab)|$ is larger than $E(a) + E(b)$. This means that the correlations between the measurements of A and B cannot be explained by classical physics.

Bell's theorem shows that if quantum mechanics is correct, then there must be some form of non-locality in nature, meaning that the properties of entangled particles are somehow linked across large distances. This has been experimentally verified through measurements of entangled particles, and has led to the development of new theories and interpretations of quantum mechanics.

In summary, Bell's theorem is a mathematical result that demonstrates a fundamental difference between the predictions of quantum mechanics and classical physics that obey locality. It shows that the correlations between measurements of entangled particles violate a mathematical inequality that holds true for classical physics, providing evidence for the non-local behavior of entangled particles in quantum mechanics.

- There is nothing inherently wrong with $|E(ab)|$ being larger than $E(a) + E(b)$ in and of itself. The significance of this inequality lies in the fact that it contradicts the predictions of classical physics and local realism.

In classical physics, the energy of a system is assumed to be additive, meaning that the total energy of a system can be obtained by summing the energies of its individual components. Thus, if two particles A and B are not entangled, the total energy of the combined system is simply the sum of the energies of A and B:

$E(A+B) = E(A) + E(B)$

However, in quantum mechanics, the properties of entangled particles are not independent, and the energy of the combined system cannot always be expressed as the sum of the energies of its components. This means that the inequality $|E(ab)| \leq E(a) + E(b)$, which would hold true in classical physics, may be violated in quantum mechanics.

The violation of this inequality implies that the properties of entangled particles are somehow linked in a way that is not possible according to classical physics or local realism. Instead, the properties of entangled particles must be inherently non-local and interconnected, a key feature of quantum mechanics.

- The concept of "reduction of the wave packet" refers to the collapse of the wave function that occurs when a quantum system is measured. When a measurement is made on a quantum system, the wave function collapses into a definite state, and the system is no longer described by a superposition of states. This collapse of the wave function is sometimes referred to as the "reduction of the wave packet," and it plays an important role in the interpretation of quantum mechanics.
- Identicne cestice su uvijek automatski spregnute - dva razlicita nacina u zavinosti od prirode cestice

projectors and density matrix for mixed states

In quantum mechanics, a projector is an operator that projects a quantum state onto a specific subspace. It is represented by a Hermitian operator P, which satisfies the properties $P^2 = P$ and $P^\dagger = P$. When a state $|\psi\rangle$ is projected onto the subspace associated with the projector P, the resulting state is given by $P|\psi\rangle$.

The density operator, also known as the density matrix, is used to describe mixed states in quantum mechanics. It is represented by a positive semidefinite, Hermitian operator ρ, which satisfies the properties $\rho^\dagger = \rho$ and $Tr(\rho) = 1$. The density operator encapsulates the probabilities and quantum coherence of a mixed state. The expectation value of an observable A for a mixed state ρ is given by $Tr(\rho A)$.

The connection between projectors and the density operator arises from the concept of pure and mixed states. A pure state can be represented by a ket $|\psi\rangle$, and its associated density operator is given by $\rho = |\psi\rangle\langle\psi|$. In this case, the projector P onto the subspace associated with $|\psi\rangle$ is equivalent to the density operator ρ.

For a mixed state, which cannot be represented by a single ket, the density operator provides a statistical description of the system. It can be written as a sum of projectors onto the subspaces associated with different pure states, weighted by their probabilities. Mathematically, the density operator for a mixed state can be expressed as:

$\rho = \sum_i p_i |\psi_i\rangle\langle\psi_i|$

where $|\psi_i\rangle$ are the pure states contributing to the mixture, and p_i are their respective probabilities.

Therefore, projectors and the density operator are closely related in quantum mechanics, with projectors being a fundamental tool to describe pure states, and the density operator capturing the statistical ensemble of mixed states.

- operator neki POSTAJE matrica kad o njemu govoris u nekom bazisu, reprezentacija
-