Three findings about memory recall and TGD based view about memory retrieval

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Abstract

I learned within a few weeks about three very interesting works of neuro-scientists relating to memory recall. This inspired a construction of a detailed TGD based model for the memory recall. The model generalizes to a model of sensory perception and motor action. The identification of motor action as time reversal of sensory perception is however sharpened: motor action corresponds to a "big" state function reduction (BSR) changing the arrow of time and sensory perception to a "small" state function reduction (SRS) preserving it. What is also new, is the combination of this picture with the old TGD based vision about living system as a conscious hologram. The idea about brain as hologram is originally due to Karl Pribram. The common mechanism of sensory perception, motor action, and memory recall would be surprisingly simple. Magnetic body would (MB) send reference beams interfering with incoming beams representing sensory input to build a hologram on living matter serving as a substrate. Phase conjugates of reference beams would be used to generate memory recall and to generate motor actions.

Contents

1 Introduction

I received within few weeks 3 highly interesting links telling about the work of neuro-scientists relating to memory recall. This inspired a construction of a detailed model for the memory recall which generalizes to a model of sensory perception and motor action based on the vision discussed in detail in [L6] (see http://tinyurl.com/ybe4vf3j). The original vision about motor action as time reversal of sensory percept is sharpened so that motor action corresponds to a "big" state function reduction (BSR) changing the arrow of time and sensory percept to "small" state function reduction (SRS) preserving it. What is also new, is the combination of this picture with the old

TGD based vision [K2] about living system as a conscious hologram. The idea about brain as hologram is originally due to Karl Pribram [J2].

A short summary of TGD inspired theory of consciousness is in order to help the reader to follow the arguments.

1. Zero energy ontology (ZEO) predicts that quantum states are superpositions of deterministic time evolutions (preferred extremals representing space-time surfaces as minimal surfaces). These space-time surfaces connect 3-surfaces the opposite boundaries of causal diamond (CD) forming a scale hierarchy. There are two kinds of state function reductions.

   Zero energy states can be regarded as pairs of ordinary quantum states located at opposite boundaries of CD and having interpretation as wave function in the space of 3-surfaces at the boundary of CD. The 3-surfaces at opposite boundaries of CD are connected by space-time surface - preferred extremal - which is minimal surface apart from 2 dimensional string world sheets and their 1-D light-like boundaries at light-like 3-D orbits of partonic 2-surfaces at which the signature of the induced metric of space-time surface changes its signature from Minkowskian to Euclidian [L8, L7].

   "Small" state function reductions (SRSs analogous to weak measurements in standard quantum measurement theory) leave the passive boundary of CD unaffected as also states at it but affect the states are active boundary, and also shift the active boundary farther away from the passive one (in statistical sense at least). Each small state function reduction is preceded by a unitary evolution of state at the active boundary meaning shift of the active boundary: actually a time-delocalization of the active boundary takes place in the moduli space of CDs. SRS involves a localization with respect to time defined by the temporal distance between the tips of CD. The correlation between experienced time and geometric time identifiable as the distance between the tips of CD follows since state function reductions identifiable as basic building bricks of conscious experience increase this distance in a statistical sense.

   "Big" state function reduction (BSR) changes the roles of the boundaries of CD and corresponds to state function reduction as it appears standard quantum measurement theory. In particular, the arrow of time as a property of zero energy state changes. The change of arrow of time is in a fundamental role in TGD inspired quantum biology and corresponds to the death of self followed by a re-incarnation with reversed arrow of time.

4. Since the superposition of preferred extremals is only replaced with a new one in state function reductions, they are consistent with the determinism of classical physics, which is an exact part of quantum TGD - space-time surfaces can be regarded as analogs of Bohr orbits. One also avoids the basic paradox of standard quantum measurement theory and there is no need for "interpretations".

5. The original somewhat fuzzy vision about motor action and sensory perception was as time reversals of each other so that the difference between them would be only relative. The recent view is more precise and implies absolute difference: Motor actions correspond to BSRs and sensory percepts to SRSs. Also memory recall can be seen as time reversal of sensory perception in a well-defined sense [?]

The model for various findings described below relies on this picture combined with the vision about living system as conscious hologram [K2]. The TGD inspired model for for the memory recall generalizes to a model of sensory perception and motor action. The common mechanism of sensory perception, motor action, and memory recall would be surprisingly simple.

Magnetic body (MB) would send reference beams R interfering with incoming beams O representing sensory input to build a sensory representation as a hologram H on living matter serving as a substrate. Conjugate hologram $\overline{H}$ would correspond to a time reversal of H constructed using conjugate beams $\overline{R}$ and $\overline{O}$. The reading of sensory percepts/memories would take place by illuminating $H/\overline{H}$ with $R/\overline{R}$ coming from MB.

An important challengeable assumption is that the time reversals of our mental images are not conscious-to-us. It implies that the reading of the memory by $\overline{R}$ does not yet produce mental image conscious-to-us: only the next BSR would generate memory representation readable by applying R. This picture is consistent with the empirical findings inspiring the detailed model.

2 The findings

In the following brief summary about findings is given.

2.1 Ripples race in the brain as memories are recalled

The first link was to a popular article in *Science News* with title "*Ripples race in the brain as memories are recalled*" (see `http://tinyurl.com/y5hohv2h`) telling about the findings of neuroscientists Vaz et al about memory recall published in Science as article with title "*Coupled ripple oscillations between the medial temporal lobe and neocortex retrieve human memory*" [J1] (see `http://tinyurl.com/y48kdkrl`).

2.1.1 Results

The results come from the study 14 patients suffering from epilepsy. They had electrodes placed on their brains as part of their treatment. The electrodes also allowed scientists to monitor neural activity while the people learned pairs of words.

One to three minutes after learning the pairs, people were given one word and asked to name its partner. As participants remembered the missing word, neuroscientist and neurosurgeon Kareem Zaghloul and his colleagues caught glimpses of fast brain waves rippling across parts of the brain at a rate of about 100 per second.

These ripples appeared nearly simultaneously in two brain regions the medial temporal lobe known to be important for memory, and the temporal association cortex having a role in language. When a person got the answer wrong, or didnt answer at all, these coordinated ripples were less likely to be present, the researchers found.

The abstract of the article provides a more technical summary.

> *Episodic memory retrieval relies on the recovery of neural representations of waking experience. This process is thought to involve a communication dynamic between the medial temporal lobe memory system and the neocortex. How this occurs is largely unknown, however, especially as it pertains to awake human memory retrieval. Using intracranial electroencephalographic recordings, we found that ripple oscillations were dynamically coupled between the human medial temporal lobe (MTL) and temporal association cortex. Coupled ripples were more pronounced during successful verbal memory retrieval and recover the cortical neural representations of remembered items. Together, these data provide direct evidence that coupled ripples between the MTL and association cortex may underlie successful memory retrieval in the human brain.*

2.1.2 Ripples as hologram

The basic question concerns the interpretation of the ripples appearing both during the formation and the retrieval of the memory. The TGD based vision about living system as a conscious hologram [K2] suggests an answer (for the notion of hologram see `http://tinyurl.com/qgjsdzz`).

1. During the sensory perception the ripples are created by the interference of the reference beam coming from magnetic body (MB) with dark photon beam representing sensory input transformed to dark photons at sensory organs as TGD inspired model for the generation of percept as forth-and-back communication between MB/brain and sensory organs assumes [L4].

2. During memory recall MB sends the phase conjugate of the reference beam scattering from the time reversed conscious hologram and generates phase conjugate beam representing the time reversal of the sensory input. At quantum level this involves BSR and the phase conjugate mental image resides at boundary of CD opposite to that carrying the ordinary mental images.

   This sensory mental image need not be conscious-to-us and this has been the assumption. The "death" of the phase conjugate mental image in a further BSR gives rise to a mental image at the "normal" boundary of CD. This mental image need not be sensory mental image (sensory/episodal memory) and could correspond to imagination or verbal memory.

There are several questions to be answered. Can one keep the earlier hypothesis that the phase conjugate sensory mental image is not conscious to us? Does the "normal" mental image correspond to sensory mental image (episodal/sensory memory) or almost sensory mental image (declarative or verbal memory)?

2.2   The human brain works backwards to retrieve memories

The second interesting link was to an popular article "*The human brain works backwards to retrieve memories*" (see `http://tinyurl.com/y7hbqmug`). The article tells about the work of Linde-Domingo & Wimber et al published in Nature Communications as article titled "*Evidence that neural information flow is reversed between object perception and object reconstruction from memory*" [J3] (see `http://tinyurl.com/y375ht5f`).

2.2.1   Results

During the study, participants saw images of specific objects, and then learned to associate each image with a unique reminder word, for example the word 'spin' or 'pull'. The participants were later presented with the reminder word and asked to reconstruct the associated image in as much detail as possible.

Brain activity was recorded throughout the task via 128 electrodes attached to the scalp, allowing the researchers to observe changes in brain patterns with millisecond precision. Finally the researchers trained a computer algorithm to decode what kind of image the participant was retrieving at different points in the task.

The abstract of the article summarizes the results.

> *Remembering is a reconstructive process, yet little is known about how the reconstruction of a memory unfolds in time in the human brain. Here, we used reaction times and EEG time-series decoding to test the hypothesis that the information flow is reversed when an event is reconstructed from memory, compared to when the same event is initially being perceived. Across three experiments, we found highly consistent evidence supporting such a reversed stream. When seeing an object, low-level perceptual features were discriminated faster behaviourally, and could be decoded from brain activity earlier, than high-level conceptual features. This pattern reversed during associative memory recall, with reaction times and brain activity patterns now indicating that conceptual information was reconstructed more rapidly than perceptual details. Our findings support a neurobiologically plausible model of human memory, suggesting that memory retrieval is a hierarchical, multi-layered process that prioritises semantically meaningful information over perceptual details.*

2.2.2   TGD vision

This picture is consistent with the general TGD vision predicting that memory recall is time reversal of sensory perception and with an entire hierarchy of levels labelled by the values of effective Planck constant $h_{eff} = nh_0$ measuring roughly the level of evolutionary hierarchy [L1, L2] and by p-adic length scales. The larger the value of h_{eff}, the longer the relevant time and length scale is, and the more abstract the representation is. The "gist" would correspond to large values of h_{eff} to which one can assign largest maximum value of information content.

2.3   Neuroscientists read unconscious brain activity to predict decisions

The third link was to a popular article "*Neuroscientists read unconscious brain activity to predict decisions*" (see `http://tinyurl.com/yxgnr9x6`). The article tells about the work of Koenig-Robert and Person published in Scientific Reports as an article with title "*Decoding the contents and strength of imagery before volitional engagement*" [J4] (see `http://tinyurl.com/yyp6hugz`).

1. In the experiment the situation was following. The subject person looked at most $T = 20$ seconds two different pictures, decided to imagine either of them, and pushed immediately

the knob. Then she tried to imagine the chosen picture. Subject person reported also the subjectively experienced intensity of imagination.

Neural activity was detected in brain and it was found that it emerged $t = 11$ second before the decision. From the pattern of activity it was possible to predict the picture. Also the subjectively experienced intensity of imagination could be predicted. One could say that the sensory experience was re-created by imagination in the brain of past.

2. The imagination involved could be also regarded as an active memory recall. This interpretation suggests that the time t at which the neural activity appears must be within the T= 20 second interval during which the decision was made.

3. The authors leave open whether their finding excludes free will. The first interpretation is that the choice really occurred at unconscious level and for some reason subject person experienced illusion of choise. A real choice combined with illusion about real choice looks rather weird idea, and only shifts the problem of free will to a level unconscious to us. If there is no free will then all experiments involving choice are pseudo experiments: this would throw a large portion of neuroscience to trash bin.

These findings will be used to build TGD based model for memory recall based on TGD based vision about living systems described in the introduction.

3   TGD based model for what happens in imagination as active memory recall

The experiments discussed above give good hopes about a detailed model for what happens in imagination as active memory recall.

3.1   Background ideas

To develop this model some background ideas about TGD are needed.

1. I have developed a model for motor action as time reversal of sensory perception based on ZEO in an earlier article [L6] (see `http://tinyurl.com/ybe4vf3j`). This leads also to a model for remory recall as sending a signal to geometric past giving rise to time reflected signal as memory recall.

   Could memories correspond to mental images in standard time direction generated by time reflected dark photon beam as has been assumed hitherto or do they correspond to time reversed mental image in the geometric past at the opposite boundary of CD. The earlier assumption has been that time reversed mental images are not conscious to us.

2. There are several words to which one must give meaning: what do "re-experience in geometric past", "time reflection", "imagination as active memory recall" mean? Who is the imagining intentional agent? The above experiment inspired an attempt to give a more precise meaning for these words.

   The idea is to combine the model of memory with a decades old model of living matter as conscious hologram [K2] (see `http://tinyurl.com/y6lz3t3y`) (one more imprecisely defined word!) .

3. Magnetic body (MB) is the basic notion. MB acts as intentional agent using biological body (BB) as motor instrument and sensory receptor. In the recent case MB imagines and performs active memory recall by selecting the picture and directing its attention to it (still more words to be explained!).

   Dark matter hierarchy as hierarchy of phases of ordinary matter (also photons) assignable to the MB and labelled by the value of effective Planck constant $h_{eff} = n \times h_0$ is a further central element of the general picture. In particular, EEG photons are dark photons with very large value of Planck constant guarantewing that their energies are above thermal threshold. Bio-photons would with energies in visible and UV range would result as dark EEG photons with very large value of h_{eff} transform to ordinary photons.

4. Brain as a hologram is an old idea originally to Karl Pribram. The formation of hologram involves two waves with the same freqeuency: reference wave and the wave representing the target - typically a wave of same frequency reflected from the target. The reference wave is a simple plane wave with some frequency. These waves must interfere so that coherence is required. The interference pattern is stored by the modification of the hologram substrate. The transmission coefficient of the substrate is proportional to $T = |vertU_0 + U_R|^2$, where U_0 and U_R are complex amplitudes.

   If one illuminates the resulting hologram by reference wave U_R the image of the target is formed. If one illuminates the target with the phase conjugate $\overline{U}_R$ of the reference wave - its time reversal $\overline{U}_0$ - the phase conjugate of the image is formed. In ZEO time reversal has precise quantal meaning as also the time reversal of self and of mental image.

   This requires coherence in the length scales of hot and wet brain. Without non-standard large enough value value of h_{eff} makes this is not possible. The coherence for ordinary photons need not be quantum coherence, but is induced by quantum coherence of dark photons transforming to ordinary photons. Quite generally, the coherence of living matter would be induced in this manner from quantum coherence of dark matter at magnetic flux tubes.

3.2   TGD inspired model for memory retrieval

With these ingredients one can build a rather simple model for memory retrieval.

1. Memory and sensory mental images is generated as MB creates a reference wave in the formation of hologram as interference pattern of incoming ordinary light beam and dark reference beam. This induces the pattern of neural activity. Coherence is not quantum coherence but inherited from quantum coherence of dark photon beam from MB. Also phase conjugate in active memory recall comes from MB. The ripples associated with the formation of sensory percept would correspond to the formation of conscious hologram.

2. Phase conjugate wave corresponds to time reversal of wave and would be created in ZEO in BSR reversing the arrow of time for self involved. The phase conjugate of the reference wave generated by MB acting as intentional agent trying to imagine would propagate to geometric past and scatter from the brain substrate acting as a hologram and generate the memory mental image in geometric past at the opposite boundary - the "re-experience", which need not be conscious-to-us. The ripples reported in the first article [J1] would correspond to the scattering of the phase conjugate wave from the hologram.

   This phase conjugate mental image need not be conscious-to-us: the assumption has indeed been that time reversed mental images are not conscious to us. The assumption will be kept also now.

   The next BSR would mean the "death" of the memory mental image and rebirth as a mental image in standard time direction. This would correspond to the "time reflection" generating a signal to the geometric future defining in the recent situation declarative, verbal memory of the mental image. This would be the outcome of imagination experienced by the subject person.

   Why these "normal" mental images are not usually genuine sensory mental images at our level of self hierarchy? A good reason for this is that they would interfere with the ordinary sensory perceptions. We can indeed have this kind of mental images during dreaming and hallucinations. During dreaming it is not a threat for survival as it is during hallucinations. I have discussed a detailed model for imagination as almost sensory mental images [L4] (see `http://tinyurl.com/ydhxen4g`). They would be created by feedback signals from MB via cortex to a level above sensory organs in the hierarchy so that no actual sensory percepts is obtained. Also imagined motor actions would be similar.

   An essential element of the model is that the sensory input is transformed to dark photons beams propagating along flux tubes parallel to axons and being responsible for the communications. The function of nerve pulses would be creation of communication channels by connecting flux tubes associated with axons to longer structures: neural transmitters

and various information molecules would do this connecting. Situation would be very much analogous to that in mobile phone communications.

The notion of re-incarnation is certainly the most controversial aspect of the proposed vision. TGD predicts self hierarchy and sub-selves are identified as mental images so that one can look whether re-incarnation hypothesis makes sense for them. After images appearing periodically would be examples of this kind of mental images: they would be conscious to us and correspond to the level of self hierarchy immediately below us. Since they are typically of different color than the original image, we know that they do not represent a real object. The periods without after image would correspond to the phase conjugates of these mental images and would be un-conscious to us. Essentially a sequence of re-incarnations of mental image would be in question.

3. How can subject person (identifiable as MB!) actively choose the target of the memory recall? In the experiment considered the two pictures were seen by the subject person for a time not longer than $T = 20$ seconds. Both generate a hologram like structure in visual cortex which in good approximation are disjoint patterns of neural activity - presumably regions of coherence induced by quantum coherence of the dark reference beam.

A conscious choise associated with the memory recall requires that the two areas are labelled by some control parameter which MB can vary. Fixing this parameter directs the attention of MB to either picture. The frequency of the laser beam is the only parameter available. Incoming beam of light corresponds to the energies of visible light and for the ordinary value of Planck constant one cannot vary the frequency. There is however EEG frequency, which can be varied but its ratio to the frequency of visible light is of order 10^{-14} for 10 Hz! The energy $E = hf$ of EEG photons is extremely small and EEG photons should have absolutely no effects on brain or correlate with the contents of consciousness. We however know that it does!

In TGD framework this fact was the original motivation for the hierarchy of Planck constants for which adelic physics [L1, L2] provides a mathematical justification. The choice of the picture to be imagined/attended by MB would mean that the value of h_{eff} associated with it changes. The chosen picture naturally corresponds to a larger value of Planck constant since the maximal conscious information content of the system increases as h_{eff} increase. The increase of h_{eff} requires metabolic energy as directed attention certainly indeed does.

EEG also requires metabolic energy and it would be non-sensical to send information to outer space without any receiver: MB is the natural receiver of this information.

4. A more refined view about memory recall motivated by the second article described above [J3] involves a hierarchical structure in which memory recall is built up so that first the "gist" of the pattern is recalled and then come the details. This is the opposite of what happens in sensory perception in which features are identified first and the holistic view emerges later.

TGD predicts self hierarchies labelled by the values of h_{eff} and by p-adic length scales. The higher the level of self hierarchy, the longer the corresponding length scale. The "gist" corresponds to large values of h_{eff} and low EEG frequencies whereas details correspond to smaller values of h_{eff} and higher EEG frequencies and smaller wavelengths for ordinary photons. The construction of the memory mental images would correspond to a cascade of state function reductions proceeding from long to short length scales and beginning from largest value of h_{eff} involved. The model for what happens in state function reduction in TGD framework assumes this cascade [K3] [L3] (see `http://tinyurl.com/yyv3v9u8` and `http://tinyurl.com/ycxm2tpd`).

5. It is essential that sensory input is transformed to dark photons at sensory organs propagating to the brain: this also makes the processing of sensory information fast and sensory mental images can be built as standardized mental images - pattern recognition - by forth-and-back signalling between brain and sensory organ combining artificial sensory input from brain with genuine sensory input. It is hard to imagine anything simpler!

6. Neural activity associated with the neural percept preserves the topography of the visual percept so that the shape of the firing pattern in cortex is same as that of object. This

cannot be however used as an objection against holography since it is the reading of the neural hologram which generates the image of the object. The topography of the hologram has nothing to do with the shape of the object.

This mechanism should generalize to the case of sensory perception and motor action as its time reversal. MB as an intentional agent would be sending reference beams and their phase conjugates at various frequencies f and values of h_{eff} serving as control knobs! The details are however far from clear. At least to me, it is very difficult to gain detailed understanding. This is to be expected, since our standard intuition of time relies on preferred arrow of time and on the identification of the experienced and geometric time. The following is one particular humble attempt.

1. Are motor action and sensory perception really mirror images as has been assumed hitherto so? The differences between them would be only relative and they would change their roles as the arrow of time is changed?

   Or could it be that the difference is absolute? Motor actions would correspond to BSRs and change the arrow of time. Sensory percepts would correspond to SRSs and preserve the arrow of time. The latter interpretation looks more natural and is consistent with the earlier intuitive but not precise enough view deduced from Libet's findings that sensory percept and motor action correspond to different arrows of time. Let us assume the latter option.

2. Sensory representation, hologram H is formed using reference beam R and object beam O entering to the active boundary of CD. Sensory experience, "reading" of H, is achieved by applying R to H. Subsequent SRSs correspond to R.

   It does not make sense to apply time reversal $\overline{R}$ to H: here the situation differs from that for the ordinary holograms. $\overline{R}$ can be applied only to $\overline{H}$ and would require BSR replacing H with its phase conjugate $\overline{H}$.

   If this picture is correct, one would say that the basic activities are printing to make H and reading of H using R. The triplet $\{R, O, H\}$ would be characterize the situation.

   The formation of H would be like printing and the application of R to it is like reading of the text. R must correspond to a SRS at the active boundary of CD.

3. Motor representation $\overline{H}$ formed using $\overline{R}$ and conjugate object beam $\overline{O}$ at opposite boundary of CD being now active would be sensory representation in our geometric past having opposite arrow of time. The hypothesis is that what is conscious $\overline{T}$ is unconscious-to-us.

   Our sensory percepts would reflect the motor actions of our temporal mirror image. This motor action has changed the arrow of time for sub-self to that for us and the signals coming from past are passively experienced by us.

4. Our (MB's) motor action - volitional act - involves BSR at some - presumably nearest - level of self hierarchy below us (MB) changing the roles of boundaries of sub-CD in question. At this level the receiver of sensory input is in the geometric past and memory is formed by $\overline{R}$ but as such is not conscious-to-us: this conforms with the findings of the articles. Only the next big state function reduction makes the memory conscious-to-us as sensory or possibly verbal memory and we can read it by making SRSs.

5. The application of $\overline{R}$ to time reversed mental image (conjugate sub-self) $\overline{H}$ would be unconscious memory for us. It would become conscious in BSR for it producing memory at our level: this conforms with the findings of the articles. The application of R to time mental image (sub-self) would be conscious-to-us precognition or sensory experience. Sensory experience are indeed known to be also predictions as is natural in ZEO in which quantum states are superpositions of entire deterministic classical time evolutions.

   Needless to add that this view is only a sketch. It is good to list the key assumptions.

1. BSRs correspond to motor actions and SRSs to sensory percepts including precognition.

2. Sub-selves with same time orientation are conscious to use but not their conjugates. I do not have a really good argument for why time reversed mental images should be unconscious-to-us.

3. Only R can be applied to hologram but not $\overline{R}$ as for ordinary holograms.

3.3 Could one demonstrate experimentally that the standard view about time is wrong?

The prevailing view in neuroscience and physics identifies experienced time with geometric time despite the fact that these two times have very different properties. In TGD framework these times are not identified but are closely correlated. TGD inspired theory of consciousness based on zero energy ontology (ZEO) [L3, L5] [K1] allows to understand the relationship between the two times and leads to rather dramatic predictions.

TGD interpretation says that in the act of free will MB sends phase conjugate signal to the brain of geometric past or stating it otherwise: replaces the deterministic time evolution of brain (and also its past) with a new one (strictly speaking, replaces their quantum superposition with a new one). This should happen also in the choice of which picture is to be imagined.

Could a modification of the experiment of [J4] replacing imagination with an activity not requiring memory recall allow to demonstrate that the standard view about time is wrong?

1. Consider a thought experiment experiment in which the subject person receives a stimulus and makes a decision to do something - not imagine but something else - during some time interval T after it. Suppose that the decision is found to be preceded by neural activity before the the stimulus appears.

   Standard view about time not does allow this since person could have decided about the reaction to the stimulus before it came (precognition would be the only explanation).

   TGD view about the relationship between subjective and geometric time allows this since the decision sends signal to the brain of the past and there is no reason why the moment in past could be before the stimulus.

2. The modification of the above experiment in this manner could mean the reduction of $T = 20$ seconds to - say - $T = 9$ seconds. If the neural activity would appear say $t = 11$ second earlier it would emerge before person has seen the pictures and one would have paradox for standard view about time. However, if the imagined picture relies on memory, this should not happen.

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