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Computational Modeling Of Episodic Memory

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ABSTRACT- **The Episodic memory is known to be the memory of history and personal events. It is essential to understand the mechanisms related to human intelligence. As per the findings of neuroscience the hippocampal region is a component of the limbic system and it is responsible for the retrieval and encoding of the episodic memory. The computational models are used to implement different memory theories[21]. This paper discusses about different computational models constructed to address various aspects of episodic memory. The limitations and future directions of episodic memory are also discussed.**

Keywords- Episodic Memory, Hippocampus, entorhinal cortex(EC),

I. INTRODUCTION.

Computational modeling is a sophisticated process implemented for the purpose of simulation and observance of complicated systems using computer science, mathematics and physics [1]. Many variables are included in a computational model that specifies the system that is intended to study. Constructing computer related models are popular in agricultural areas, biomedical areas, construction areas etc.

Episodic memory is a term which can be encountered in the field of neuroscience. Episodic memory can be referred as the ability possessed by a living being to recall previous events which were experienced, and recognize the past encountered experiences. There are three major regions responsible for the recollection of this memory. They are the hippocampus, prefrontal cortex and the perirhinal cortex [2] Episodic memory reference to past personal events and it is more like time travelling mentally[23].

In order to explain and simulate the episodic memory traces computational modeling can be utilized. There are several computer models constructed to explain the complex procedures which occur in the neuron levels within the human brain. Computational modeling assist the researchers to model the activities that occur in the brain with the use of graphically representing diagrams and figures while addressing the naturalistic behavior in hippocampus, prefrontal cortex and peripheral cortex [3].

II. OVERVIEW.

The study basically focuses on the computational modeling of the episodic memory There are numerous real value and complex value models that discuss about the mechanisms of episodic memory. The change of voltages between the inner and outer membranes during the transmission of signals[11]. The study further focus on the models constructed to refer transmission of signals from different regions of hippocampus like CA1 to CA3 [14]. The memory traces that are stored in the short term memory is based on interference and not decay[20]. Based on this different computational models are built.

Also different mathematical equations are elaborated in the study which explains the activities of the hippocampal region, the activation of genes in memory storing and its retrieval [11]. The architectures used to build up the computational models are also briefly discussed. The further work and issues in the research area is also discussed. The study also elaborate on a few practicles conducted by different researchers during their respective researches. Computational modeling is used in almost all of the fields like chemistry, physics, biology, economics, accounting, logistics management etc. Out of them it is very famous in the field of neuron science where the activities of the brain are simulated using these constructed models.

III. MAJOR RESEARCHES IN EPISODIC MEMORY USING COMPUTATIONAL MODELING.

A computational model is needed to be built that can describe the transforming of many memories during various behavioral events in the hippocampal region in order to restore the cognitive functions that are memory dependant[24]. These models can be used for developing prosthetic devices. The model checks the feasibility through estimation and validation of the multiple output and multiple input model named non-linear dynamic model of the CA1-CA3. The spike trains generated by the CA1 (output) and CA3 (input) related to different event during the DNMS(Delayed non-match to sample) job/task are used to model this. For this research Long-Evans male rats were trained to perform a spatial DNMS job that consists of a randomly happening delay with variable time intervals. During the sample phase the rat is required to press one lever from the given two levers: right and the left lever. The response given by the rat is

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noted as the sample response. Once the sample response is recorded the levers are retracted and a delay phase is started. During this delay phase the rat is required to find the light attached to an apparatus on the opposite side of the wall. It has to nose-poke it. Once the delay phase is over the nose-poke light is extinguished and the animal should press the other lever apart from the lever chosen in the sample phase which is protruding from the wall. This phase is called as the non-match phase where the rat is rewarded if done properly. This research consisted of 100 such trails which were utilized for the purpose of deriving conclusions. The spike trains were taken from all the rats that performed the DNMS task using a multi-electrode array. The obtained spikes were then sorted, discretized and time-stamped. This multiple-input multiple-output(MIMO) dynamics model that underlay the CA3-CA1 spike train use Volterra kernel strategy to model it[14]. Tasks involves the selection of the lever in the delay phase and in the non-match phase. These spike patterns are presented in the hippocampus as spatial-temporal patterns. The transformation of these spikes from the CA3 region to the other hippocampal region CA1, is formulated as an estimation of MIMO that is decomposed into a collection of multiple-input single-output (MISO). The mathematical equation is as follows: w=u(k,x)+a(h,y)+ε (σ), y={0 or 1} x refers to the input(CA3) spike trains. Y denotes the output(CA1) spike trains. 'w' denotes the threshold potential of the membranes of output neurons. Also these estimated model does it's validation using the Kolmogorov-Smironv test. The confidence intervals are 95% or 99%[14]. For the purpose of addressing the segmented experiences into different episodes and organizing them in order to retrieve them if needed. an architecture known as ICARUS is used[13].

The gene level signaling of LTP and STP in the episodic memory has another model. The STP and LTP are known as the primary cascade that is needed in establishing episodic memory[11]. The interactions related to different receptor gene- clusters are considered in this research. This model estimates the activities related to different genes specified for the episodic memory creation[11]. Following formula is derived to calculate the membrane voltage [11]: Cm (dVm/dt)= I_{AMPA}-I_{NMDA}-I_{GluR}-I_{leak}+I_{inj}

The model done by Lokendra Shasthri is designed to construct experiences as situations and events using a cognitive apparatus. Then these are denoted as patterns over the HLCC(high level cortical circuits). These patterns are then projected to the EC(entorhinal cortex). The result in EC can be seen as an event presented to the HS(hippocampal system) by HLCC enabling memorizations possible. The activity which was injected into the EC is propagated through a complex loop which comprises of

EC, DG(dentate gurus), CA1, CA3, CA2, and SC(subicular complex) and back to EC. During the flow of activity through this loop it triggers a synaptic change in the above stated structures. Model demonstrates that such synaptic variations could transform transient activity patterns to an unwavering structural encoding ails memory trace that consist of functional circuits [10].

The above models are comprised of only real values. The model done by Ashraya Samba Shiva, Mandar Gogate discussed below use complex numbers and real numbers. The imaginary and the real parts of the equations separately solved. The CA3 collateral within the hippocampal region comprises of pyramidal neurons and inhibitory inter neurons. The model consists of 2N + 2 equations where N is the number of excitatory neurons [9]. The results are collected and formed in the Cartesian form x + jy. If the measured actual voltage of the membranes of neurons is u, once it is written in the polar form it is : u = u_i(cos(ϕ) + jsin(ϕ)) where u_i denote the real voltage value and ϕ denotes the frequency related to the theta oscillations that range between 4 – 10 Hz. The values for the ϕ is calculated by measuring the frequencies of the respective theta oscillations. $\phi = (2\Pi f_1 t,\ 2\Pi f_2 t)$ where f_1 and f_2 are 4 and 10 Hz respectively. Therefore $\phi = (8\ \Pi t\ ,\ 20\Pi t)$. Once the inputs and the complex weights are inserted the Differential equation it is as follows : $\tau\int du_i = \int\{-u_i + \sum_j J_{ij}\, g_u(u_j) - \mathrm{h}g_v(\mathrm{v})\, u_i + I_i^{\rho p} + I_i^{MF}\}\,\mathrm{dt}$. Here the imaginary and real parts of the weights and inputs $(J_{ij},\ u_i)$ are given separately[9].

Apart from integration techniques statistical methods like regression also used in different models. The formation of hippocampal plays a major role in formation of lasting representation of events. But the events are temporally and spatially connected processes. This model has the ability to represent the casual events stored in the hippocampus to define various events by utilizing a signal encoding mechanism in the model. The model is applicable on the spatial inputs. It's various parts can feature the periodical neural activities in the entorhinal cortex and in the hippocampus. $s(t + 1) = \sum_{i=1} f_i\, s(t - i) + \sum_{j=0}^{J} Hje(t + 1 - j)$ [8]. Some computational models use the commonly implemented Hebian learning rule to derive their model. All of these mathematical equations describe the algorithmic tasks of different functions. The first function is to estimate the innovation function; $\hat{n}(t + 1) = x(t + 1) - \widehat{M}\, x(t)$ The cost function corresponding to the above stated innovation function is $J(\widehat{M}) = \frac{1}{2}\sum_t |x(t + 1) - M\mathrm{z}(t) + \widehat{\mathrm{Qv}}(t + 1)^2|$ derived based on the given Hebian Rule $\Delta\widehat{M}(t + 1)\ \alpha\hat{n}(t + 1)x(t)'$ and the dash sign refers to the transpose[14].

IV. CURRENT ISSUES

Cognition related episodic models should have a mechanism to facilitate accessing of different experiences related to the past activities. Also the models should be

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standardized to compare with human episodic memory handling[6].The hippocampal model encounter problems due to the accumulation of noise in the phase of mental travelling[6].Another issue in the model is, the recalled items in the episode are assumed to be correct in the serial recall approach [6]. Due to this assumption if the recalling fails in the mid way then the cascade is broken and the entire recalling should be terminated which is not the case in the real memory[6]. As the sampling of the captured signals are coarse and lack the digital cues the place fields are transverse within a single step. But in real scenarios place cells within the brain are activated for several theta periods [8]. Also a full description of HR (hippocampal region) is not provided. A major projection locality of the CA1 region known as the subiculum is not modeled [8]. In the complex-valued model the phase function is not being defined in the derived equations [9]. Also the decisions derived about input stimulus are highly dependable on the phase of the theta oscillations [9]. In the STP LTP model the simulation of it is based on the parametric values which are extracted from the literature. The created CLS hippocampal model has only incorporated a crude version related to mode setting [10].

Furthermore the current models do not support the phenomena of forgetting and is assumed that episodic memory is long period based cue system [13]. There are models where statistics and estimation is used. Here the output value of CA1 is predicted based on the CA3 input by the model [14]. The chosen data structure depends on the scale of the implemented model and not based on a theoretical distinction is constructed based on the Hinizman's assumption [15]. The constructed model is specified to handle the timed responses of the episodic memory but not the other particular aspects of episodic memory. Especially the sequential ordering of the memory traces [16].

V. APPLICATIONS OF COMPUTATIONAL MODELING.

Computational modeling is in many fields. The episodic memory which is a part of neuroscience use computational models to describe, simulate and address various malfunctions in the hippocampal and neocortex regions of the human brain[25]. The models developed for the episodic memory are used for the regeneration of lost memory, for modeling neural of the brain[10]. Also the model proposed by Sudhakar Triapthi and R. B. Mishra for gene level signaling for STP and LTP [11].Furthermore computational models are used to predict the damage caused to the EC [10].

VI. DISCUSSION

Computational modeling can be considered as one of the fundamental building blocks in neuroscience. Episodic memory is popular among the neuron scientists, for there are many unrevealed facts related to episodic memory in the hippocampal region. The

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methodologies adapted to demonstrate the activities that occur within the hippocampus are discussed. There are different mathematical approaches to address various aspects of episodic memory. These diverse approaches as well as their shortcomings are broadly discussed. Furthermore the future directions are discussed below.

VII. COMPARISON OF SOME RESEARCHES

Title	***Aim or Problem addressed***	***Limitations/Problems faced***	***Future Directions***
A Cognitive Model of Episodic Memory Integrated with a general cognitive architecture.	A framework is presented in order to describe the functional stages for the computational model in episodic memory.	2) Abandoning of pilot approach that can trigger encoding. Also the appropriate trigger that has to be used in initiation is not clear.	1) Need of applying the model for more complex tasks and for human data.
A Reservoir Computing model of episodic Memory	1)RC architecture implemented to reconstruct and memorize image sequences for representing in the episodic memory.	2) Accumulation of noise once mental travelling commence with time.	1) Evolving of the model more biologically.
Autoregressive model of the hippocampal representation of events.	1) Translation of algorithms into a connected network.	1) The switching of separate environments have to be changed.	1)Full description of HR is not yet provided by the current model.
Complex Valued Computational model of hippocampal CA3 Recurrent Collaterals	1)A model related to CA3 region that include complex inputs and weights with results being simulated.	1)The phase equation is not defined.	2)The phase equation should be connected with the CA3 complex valued model.
A computational model of STP and LTP for gene level signaling cascade in human episodic memory.	1)A model which discusses about the gene level signaling of episodic memory.	2) Calcium influx is dependent on frequency inputs.	1) Can be utilized for discovering disorders and for finding relevant drugs and therapies for the disorders.
Computational Models of Episodic Memory.	1)To represent how to address the neural structures mentioned above.	1)Risk of blending of the old and new memories stored in the hippocampus due to the Hebian theory used .	1)Designing of new memory models that can address the shortcomings of the prevailing models.
Computational models of memory.	1)The approaches taken to construct different memory models.	1)Neural plausibility is the basis for evaluation of models which could be a single point of failure.	1) Bridging the gap of the three different classes of computational models to increase the realism.
Episodic memory in a Cognitive Model.	1)Agent learning through observations and extension of enabling episodic memory in ICARUS a cognitive architecture.	1)The assumption made that episodic memory is a long term memory cue and does not support forgetfulness.	1) Introduction of cognitive reasoning in the ICARUS.
Estimation and Statistical validation of Event-Invariant	1)Development of a statistical model to test the functionaliti	1)Event specificity is not available for the system and the CA1 output is predicted based on the CA3 input.	1)Achieving of event variability.

Nonlinear Dynamic models of Hippocampal CA3-CA1 Population Activities.	es of the regions within the hippocampus (CA1, CA3) and evaluate the constructed model.		
A Framework for Computational Models of Human Memory.	1) Analysis of existing memory models and introduction of a theoretical framework that can characterize memory modeling .	1)The data structure used is not independent of the memory model.	1)To explore answers to questions like why people are fast in remembering some while slow in remembering other things. The reason behind the time variance of memory retrieval.
A biophysical computational model for memory trace transfer from hippocampus to neocortex.	1)A biophysical model that includes the layerV and CA1 networks related to the prefrontal cortex to explore the possible ways by which the memory traces located in the hippocampus being transferred to the prefrontal cortex.	1)Based on the weakness of PY-PY connections in the network which is untrained the PY cells located at the very beginning cannot generate larger PSP.	1) The hippocampal- cortical coordination which is ripple based need to be analyzed further.

VIII. FUTURE DIRECTIONS

Investigations needed to be done to know the reasons for forgeting of some and retaining of other memories. A way to implement parallel algorithms that reach a fixed time. Also the relationship among episodic memory and semantic memory have to be explored. Further reserch on utilization of episodic memory on reflective learning[6]. Invariance related to input space have to be further studied[8]. The phase function in the complex value model have to be incorporated with the CA3 model if advanced neurobiological and mathematical analysis and validating is expected to be done[9]. If the signal cascading model is further developed it will be helpful to estimate related gene disorders, estimating of different gene activities and coming up with therapies and drug solutions for those disorders [11]. Improved or new cognitive functionalities that are related to case-dependent reasoning for ICARUS[13]. More evaluation in deeper understanding of episodic memory is needed in terms of dynamics and representation[17]. Further researches can be conducted to develop computational models that discuss induction of parallel memory of human. As the researches are still limited to Wistar Rats[19].

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