A Comparative Analysis of Episodic Memory Between Humans and AI Agents with Context Correlation

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Presenters

VEDANT GHATNEKAR

I am a student from MIT-WPU, Pune studying BTech in Mechanical Engineering. My research interests include Cognitive Robotics, Human-Robot Collaboration, Memory in AI Agents, Reinforcement Learning and Deep Learning. I have been pursuing these interests in my various projects and internships to build a deep and intuitive understanding of various concepts in these fields. I have published multiple papers on the reinforcement learning models and their memory architectures that I have worked on. My eventual career goals include building collaborative robots that help people in their day-to-day lives as well as improve the quality of life of elderly or differently-abled people.

ANANT PRATAP SINGH

I am a student at VIT, Chennai studying B.Tech. in Computer Science Engineering with Specialization in AI and Robotics. With a passion for cutting-edge technology and a desire to shape the future, deeply fascinated by the potential of artificial intelligence and robotics to transform various industries. Through hands-on projects and research experiences, skills in programming, data analysis, and problem-solving, ensure a well-rounded understanding of the field. With a commitment to innovation and an eagerness to contribute to the ever-evolving landscape of AI and robotics, I want to make a significant impact in this exciting field. I am working towards improving my knowledge in this field and wish to work on Artificial Intelligence for robots in the future.

Introduction

- Episodic memory is fundamental to human cognition, enabling recalling specific past events and contextual details.
- It allows individuals to mentally revisit past experiences, integrating sensory perceptions, emotions, and spatial-temporal context.
- Episodic memory facilitates navigation of daily life, learning from experiences, and decision-making processes, shaping our identity.
- Advancements in AI have led to the development of AI agents with memory systems, mimicking cognitive processes such as encoding, retrieval, and learning.
- Our study explores the impact of context on memory encoding, retrieval, and associative processes in humans and AI.
- Our comparative analysis aims to elucidate similarities and differences between human cognition and AI memory mechanisms.

Methodology

- We create two experiments that test the memory and how contextual cues affect the performance of 4 of our human subjects with an AI model.
- We use EEG imagery to see the differences in brain activations in-between our human subjects and how it correlates with their performance.
- Our experiments are in the form of games made in Unity game engine and we interface these games with our AI model using the MLAgents toolkit and Gym API.
- The contextual cues differ in each experiments and the human subjects are allowed to explore the game just like the AI model is during it’s training.
- Our AI model uses Transformers and chunking to mimic contextual effects on human memory and was trained on our experiments using Reinforcement Learning before being tested.

Human Memory

Episodic memory in humans involves:

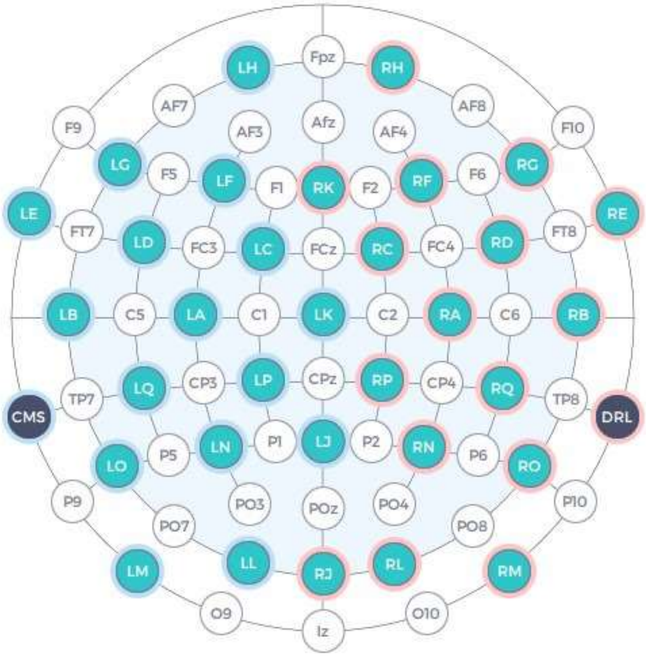
- Encoding: Sensory information is processed and integrated into memory networks, with contextual cues playing a crucial role.
- Storage: Memories are stored in the hippocampus and cortical networks.
- Retrieval: Memories are accessed using contextual cues that match the encoding context. We emulate this in our AI model using chunking as explained later.
- Reconstruction: Memories are reconstructed during retrieval and can be influenced by prior knowledge and biases.
- Forgetting: Memories can decay over time or be distorted by interference from other memories or cognitive processes.

EEG Device

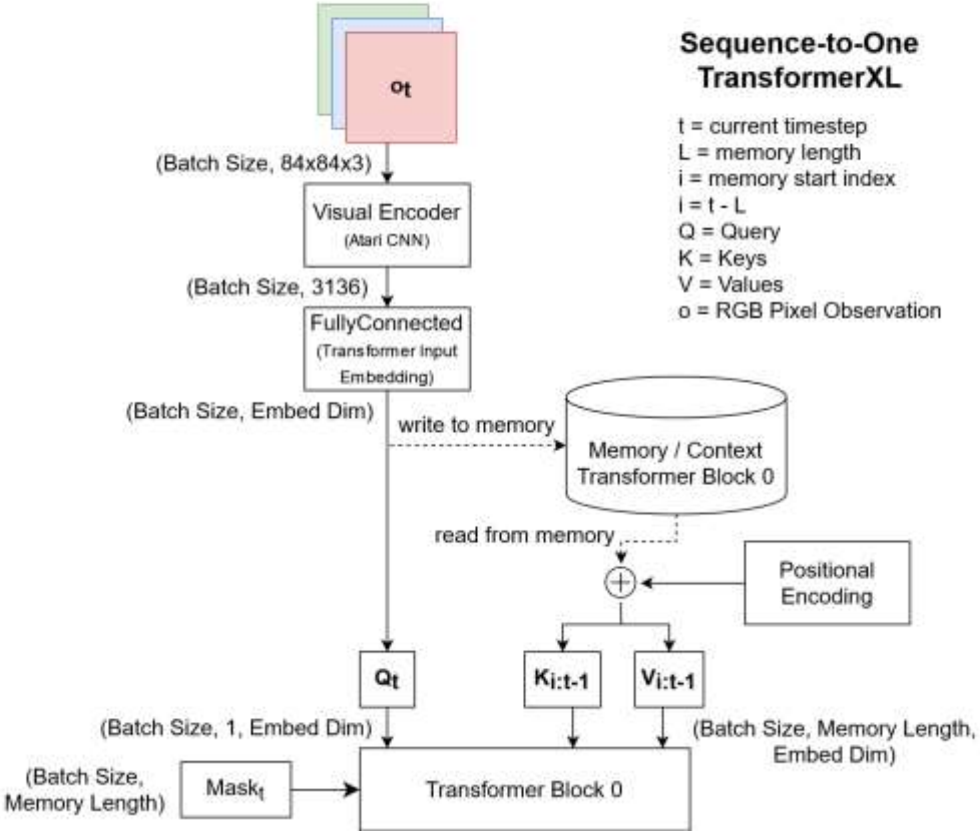
- Emotiv FLEX Gel is a research-grade, 32-channel EEG system designed for capturing detailed brain activity.
- Unlike traditional wired EEG setups, FLEX Gel utilizes a wireless design, offering researchers the freedom to conduct studies in various environments without compromising data quality.
- This portability, coupled with the high-density sensor placement, allows for comprehensive and flexible recording of brain signals.

EEG Electrode Positioning

- EEG data was collected using an Emotiv FLEX EEG cap, featuring 32 channels for recording neural activity during both encoding and retrieval phases in human participants.
- This cap comes equipped with monopolar gel-based electrodes strategically positioned across the scalp to capture electrical signals from various brain regions.
- Electrode placement adhered to the 10-20 international system for EEG electrode positioning (refer to Figure), ensuring standardized and precise positioning for reliable data acquisition.



AI Architecture



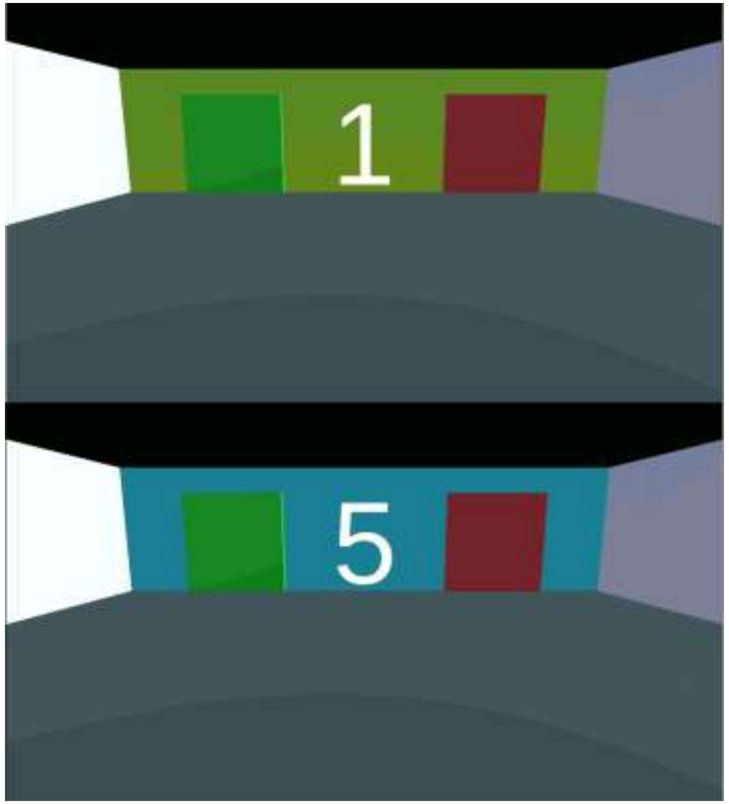
- Our main architecture which is built on a decoder-only TransformerXL backbone, applies Automatic chunking on the memory buffer to select a relevant subset of the memory buffer in view of the current context.
- Visual observations are used which are pre-processed by a three layer convolutional encoder and stored in the memory along with being used as the query at the current timestep.
- The memory buffer is then split into chunks and each chunk is assigned a summary value by mean pooling. Attention is performed using the query and these summarized values to select the top-k relevant chunks.

AI Architecture

- These chunks are then pooled together and used as the new summarized memory buffer in the transformer block. The output of the transformer is then used to calculate a categorical distribution over the action space using a linear layer.
- This lets the transformer work on chunks of more relevant memories which improves the quality of the predicted output similar to human memory.
- PPO2 (proximal policy optimization) is used to perform consistent parameter updates and to limit how far we can change the policy in each iteration.
- We test our model in the unshuffled and shuffled version of Experiment 1 which test the contextual memory and visual navigation ability of the agent.

Experiment 1

- Objective: Investigate impact of contextual cues on episodic memory encoding and retrieval in humans and AI.
- Methodology: Two participants (20-30 years old) and our AI model were tested.
- Game-Based Task: Participants engaged in a game with 20 rooms, each with numbers (1-20) and distinct wall colours. They selected a door to progress.
- Encoding Phase: Participants memorized the correct door in each room. The rooms were ordered by number and not shuffled.
- Retrieval Phase: Participants replayed the game relying on memory. The rooms were shuffled so participants had to remember the correct door related to the context instead of remembering the sequence of doors.
- Context: Wall colours served as contextual cues.



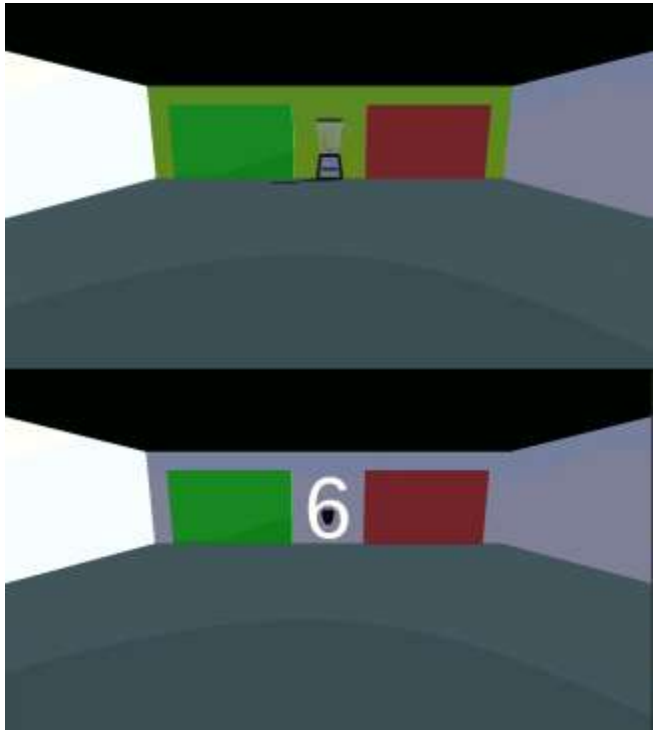
Experiment 1 Human Results

- Human participants demonstrated enhanced memory performance with contextual cues during both encoding and retrieval phases.
- EEG data indicated consistent neural correlates associated with memory processes in humans.

	Recalled	Forgets	Correct	Incorrect
Subject A	19	1	17	2
Subject B	18	2	16	4

Experiment 2

- Objective: Explore the influence of diverse contextual cues on context-dependent memory retrieval and episodic memory association.
- Methodology: Two individuals familiar with the game environment participated. They navigated through 20 rooms with varied contextual cues.
- Game-Based Task: Participants played a game where each room contained one out of 20 objects and two doors, selecting the correct door to progress.
- Encoding Phase: Participants played the game twice to associate contextual cues with correct door choices. The rooms were unshuffled.
- Retrieval Phase: Participants recalled the associated context for each room and selected correct door choices based solely on episodic memory. The rooms were shuffled during the retrieval phase.
- Context: The objects, wall colours and numbers all served as context in this experiment



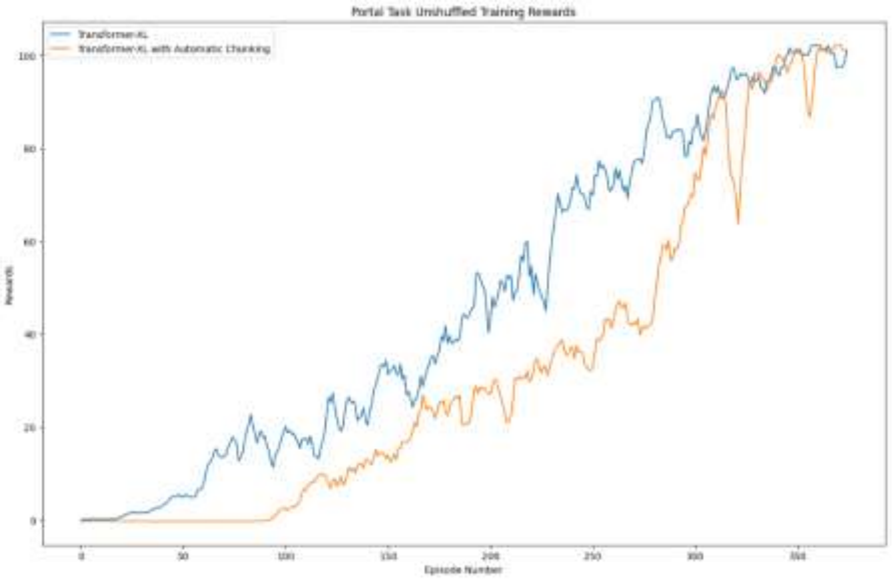
Experiment 2 Human Results

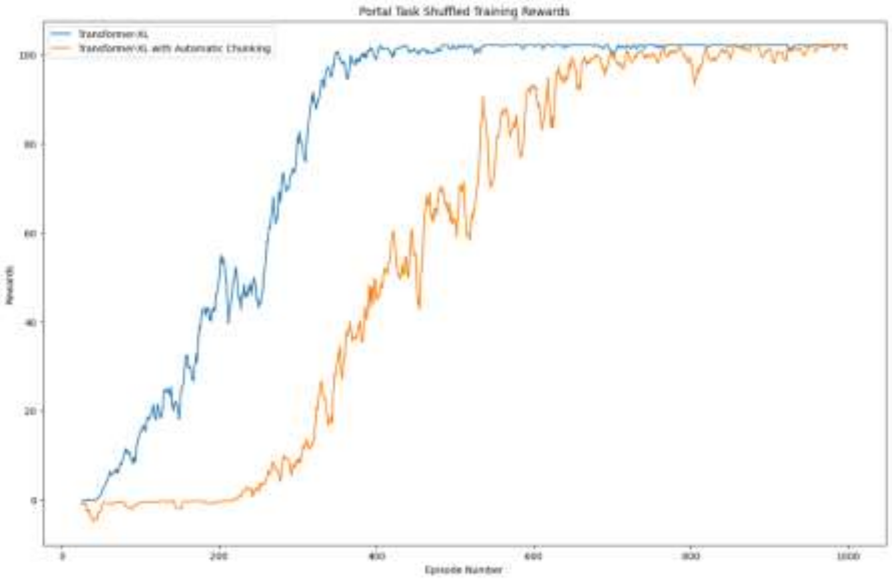
- Human participants demonstrated enhanced memory recall and association with diverse contextual cues.
- Humans successfully recalled context-associated information during retrieval tasks.

	Recalled	*Forgets*	*Correct*	*Incorrect*
Subject C	18	2	15	3
Subject D	12	8	6	6

AI Results

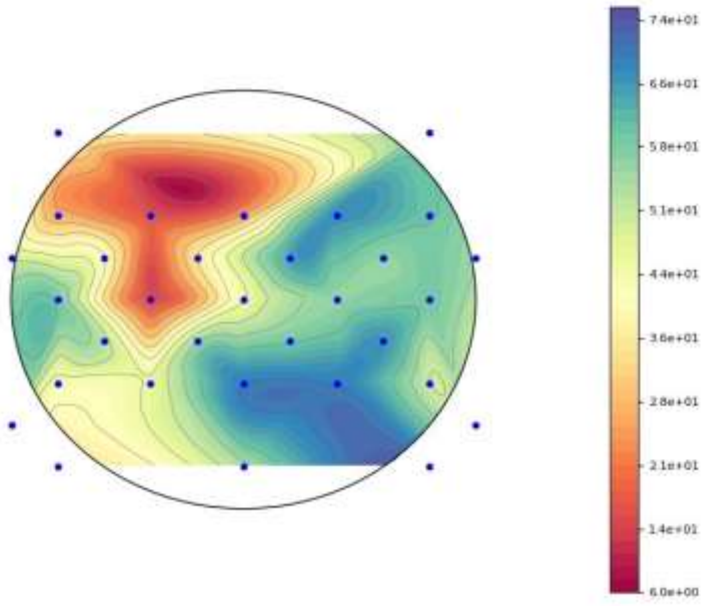
- The AI model showed improvements in memory encoding and retrieval with contextual cues over humans.
- It was able to remember the correct door choice based on the context 100% of the time.





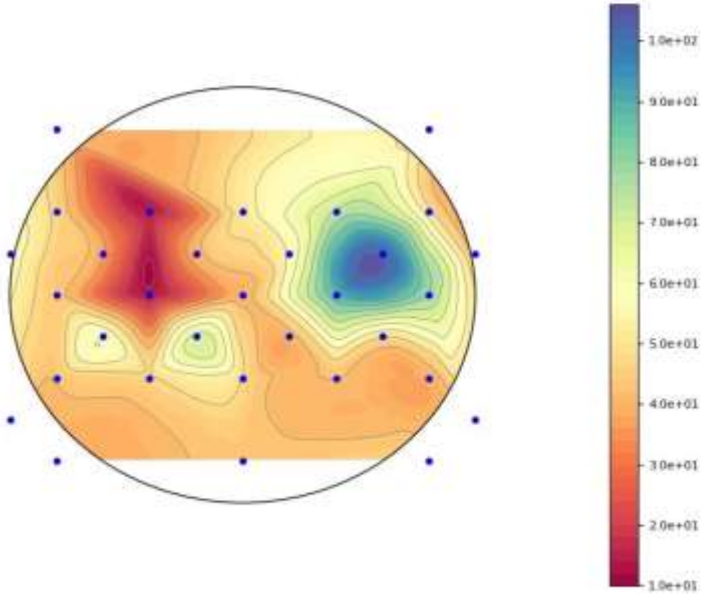
Results

- During Encoding, the Medial Temporal Lobe (MTL), Prefrontal Cortex (PFC), and parietal regions showed significant activation.
- This suggests the involvement of brain regions associated with memory formation, executive functions, and cognitive processing.



Results

- Unexpectedly during Retrieval, the MTL did not exhibit activation.
- This challenges traditional views on memory retrieval and suggests the involvement of alternative brain regions, possibly including the PFC.
- Further research is needed to understand the neural mechanisms underlying memory decoding processes.



Discussion

- The findings from both Experiment 1 and Experiment 2 highlight the critical role of contextual cues in memory recall and decision-making during game-based tasks. Individual differences were evident in memory retrieval abilities and the influence of contextual cues on episodic memory association.
- In Experiment 1, variations in in-game performance among participants underscored differing abilities in memory recall and decision-making. Subject A demonstrated efficient memory recall and navigation through the game, while Subject B experienced challenges in progressing through the game, indicating difficulties in memory recall or decision-making.
- Experiment 2 further emphasized individual differences in recalling context and associating it with correct box choices. Subject C exhibited limitations in episodic memory recall and association with contextual cues, whereas Subject D showcased robust episodic memory association with contextual cues.
- Overall, these results suggest that vivid contextual cues play a crucial role in enhancing memory recall and performance. The findings underscore the importance of considering individual variations in memory retrieval abilities and the impact of contextual cues on episodic memory association. Understanding these factors can inform the design of interventions or strategies aimed at optimizing memory recall and decision-making in various cognitive tasks.

Conclusion

- While human memory exhibited variability in recall capabilities, AI demonstrated consistent retrieval abilities, devoid of cognitive constraints.
- Neural activation patterns during encoding and retrieval phases provided insights into underlying mechanisms, aligning with previous research on memory processes. Moreover, human memory showed susceptibility to time-dependent fading, with clear contextual cues enhancing recall and association.
- These findings have significant implications for cognitive research and AI development, suggesting potential strategies to optimize human memory recall and refine AI systems to emulate or adapt to human-like memory constraints.
- AI's superiority in encoding capacity, retrieval speed, and consistency highlights its potential to revolutionize memory-intensive tasks across various domains. AI agents surpass human performance in these tasks due to the lack of memory decay over time unlike humans.
- Our future investigations aim to expand sample sizes, enhancing understanding of brain activity patterns and advancing cognitive research and AI development.

Thank You!

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