Novelty Assessment Report

Paper: Building spatial world models from sparse transitional episodic memories
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Abstract

Many animals possess a remarkable capacity to rapidly construct flexible cognitive maps of their environments. These maps are crucial for ethologically relevant behaviors such as navigation, exploration, and planning. Existing computational models typically require long sequential trajectories to build accurate maps, but neuroscience evidence suggests maps can also arise from integrating disjoint experiences governed by consistent spatial rules. We introduce the Episodic Spatial World Model (ESWM), a novel framework that constructs spatial maps from sparse, disjoint episodic memories. Across environments of varying complexity, ESWM predicts unobserved transitions from minimal experience, and the geometry of its latent space aligns with that of the environment. Because it operates on episodic memories that can be independently stored and updated, ESWM is inherently adaptive, enabling rapid adjustment to environmental changes. Furthermore, we demonstrate that ESWM readily enables near-optimal strategies for exploring novel environments and navigating between arbitrary points, all without the need for additional training. Our work demonstrates how neuroscience-inspired principles of episodic memory can advance the development of more flexible and generalizable world models.

Core Task Landscape

This paper addresses: **Constructing Spatial World Models from Sparse Episodic Memories**
A total of **50 papers** were analyzed and organized into a taxonomy with **18 categories**.

Taxonomy Overview

The research landscape has been organized into the following main categories:
- **Neuroscience Foundations of Spatial and Episodic Memory**
- **Computational Models of Spatial and Episodic Memory**
- **AI Architectures for Memory and World Modeling**
- **Human Behavioral and Cognitive Studies**
- **Theoretical and Integrative Perspectives**

Complete Taxonomy Tree

- Constructing Spatial World Models from Sparse Episodic Memories Survey Taxonomy
- Neuroscience Foundations of Spatial and Episodic Memory
  - Hippocampal Spatial Representations and Place Coding (4 papers)
  - [9] Hippocampal place cells, context, and episodic memory (David M. Smith, 2006) View paper
  - [17] Hippocampal spatial view cells, place cells, and concept cells: View representations (Edmund T. Rolls, 2023) View paper
  - [23] The human hippocampus and spatial and episodic memory (Neil Burgess, 2002) View paper
  - [34] A stable home□□base promotes allocentric memory representations of episodic□□like everyday spatial memory (Nicola Broadbent, 2020) View paper
  - Temporal and Non-Spatial Hippocampal Coding (3 papers)
  - [10] Complementary representations of time in the prefrontal cortex and hippocampus (Wing Ning, 2022) View paper
  - [24] Distributed Temporal Coding of Visual Memory Categories in Human Hippocampal Neurons (Xiwei She, 2024) View paper
  - [38] Episodic memory: Neuronal codes for what, where, and when (JÃ¸rgen Sugar, 2019) View paper
  - Neural Mechanisms of Episodic Memory Formation and Retrieval (4 papers)
  - [1] A non-Hebbian code for episodic memory (Rich Pang, 2025) View paper
  - [12] Cortical Reactivation of Non-Spatial and Spatial Memory Representations Coordinate with Hippocampus to Form a Memory Dialogue (HaoRan Chang, 2022) View paper
  - [42] Abrupt hippocampal remapping signals resolution of memory interference (Wanjia Guo, 2021) View paper
  - [46] Cracking the neuronal code of episodic memory (Jasmin Steudler, 2023) View paper
  - Hippocampal-Entorhinal Integration and Memory Dynamics (2 papers)
  - [3] Dynamic neural representations of memory and space during human ambulatory navigation (Sabrina L. Maoz, 2023) View paper
  - [8] REMI: Reconstructing Episodic Memory During Internally Driven Path Planning (Wang Zhaoze, 2025) View paper
- Computational Models of Spatial and Episodic Memory
  - Unified Spatial-Episodic Memory Architectures ★ (5 papers)
  - [0] Building spatial world models from sparse transitional episodic memories (Anon et al., 2026) View paper
  - [5] Unifying spatial and episodic representations in the hippocampus through flexible memory use (Xiangshuai Zeng, 2025) View paper
  - [7] High-capacity flexible hippocampal associative and episodic memory enabled by prestructured â□□spatialâ□□ representations (S Chandra, 2023) View paper
  - [21] Episodic and associative memory from spatial scaffolds in the hippocampus (Sarthak Chandra, 2024) View paper
  - [40] A unified model of spatial and episodic memory (Edmund T. Rolls, 2002) View paper

Narrative

Core task: constructing spatial world models from sparse episodic memories. This field bridges neuroscience, cognitive science, and artificial intelligence to understand how agents—biological or artificial—build coherent representations of space from fragmentary experiences. The taxonomy reflects a multifaceted landscape: Neuroscience Foundations examine the neural substrates of place cells, grid cells, and hippocampal remapping that underpin spatial coding; Computational Models translate these insights into algorithmic frameworks for memory consolidation and retrieval; AI Architectures explore how modern machine learning systems can leverage episodic buffers and world models for navigation and planning; Human Behavioral Studies probe the cognitive strategies people use to integrate spatial context with event memory; and Theoretical Perspectives seek unifying principles that link these domains. Representative works such as Unifying Spatial Episodic[5] and Prestructured Spatial Representations[7] illustrate efforts to merge spatial and episodic streams into coherent architectures, while studies like Dynamic Neural Navigation[3] and Planning from Imagination[2] demonstrate how agents can exploit sparse memories for flexible decision-making.

Several active lines of work highlight key trade-offs and open questions. One strand focuses on how episodic retrieval mechanisms—ranging from non-Hebbian codes (Non-Hebbian Episodic Code[1]) to agentic control strategies (Agentic Episodic Control[4])—can scaffold spatial reasoning when observations are incomplete. Another explores the role of prestructured representations versus learned

world models, debating whether spatial scaffolds (Spatial Scaffolds[21]) or latent generative models (Latent World Models[11]) better capture the flexibility of human-like memory. Spatial World Models[0] sits within the Unified Spatial-Episodic Memory Architectures branch, closely aligned with Unifying Spatial Episodic[5] in its emphasis on integrating sparse episodic snapshots into a coherent spatial framework. Compared to Prestructured Spatial Representations[7], which assumes innate geometric priors, Spatial World Models[0] appears to prioritize learning from episodic experience, reflecting a more constructivist stance on how world models emerge from memory.

Related Works in Same Category

The following **4 sibling papers** share the same taxonomy leaf node with the original paper:

1. Unifying spatial and episodic representations in the hippocampus through flexible memory use

Authors: Xiangshuai Zeng, Jon Recalde, Laurenz Wiskott, Cheng Sen, Sen Cheng | **Year/Venue**: 2025 • bioRxiv | **URL**: View paper

Abstract
N/A

Relationship Analysis
Both papers belong to the Unified Spatial-Episodic Memory Architectures category, focusing on integrating spatial navigation and episodic memory within computational frameworks. The candidate paper appears to address flexible memory use in the hippocampus, likely exploring how spatial and episodic representations can be unified through adaptive memory mechanisms. The original paper (ESWM) differs by specifically constructing spatial world models from sparse, disjoint episodic memories using transformer-based architectures with meta-learning, emphasizing rapid adaptation to environmental changes and zero-shot generalization to novel environments without task-specific training.

2. High-capacity flexible hippocampal associative and episodic memory enabled by prestructured â□□spatialâ□□ representations

Authors: S Chandra, S Sharma, R Chaudhuri, I Fiete | **Year/Venue**: 2023 | **URL**: View paper

Abstract
â□¦ models of its role in episodic memory. Here we present a â□¦ , spatial memory, and episodic memory by factorizing content â□¦ are essential for constructing episodic memory: they enable â□¦

Relationship Analysis
Both papers belong to the Unified Spatial-Episodic Memory Architectures category, integrating spatial navigation and episodic memory within single computational frameworks. The original paper (ESWM) constructs spatial world models from sparse, disjoint episodic transitions using transformer-based architectures with meta-learning, while the candidate paper focuses on hippocampal associative and episodic memory using prestructured spatial representations with factorized content. The key difference is that ESWM emphasizes rapid adaptation from minimal episodic memories without sequential trajectories, whereas the candidate paper leverages prestructured spatial scaffolds to enable high-capacity memory storage.

3. Episodic and associative memory from spatial scaffolds in the hippocampus

Authors: Sarthak Chandra, Sugandha Sharma, Rishidev Chaudhuri, I. Fiete, Ila Fiete | **Year/Venue**: 2024 • bioRxiv | **URL**: View paper

Abstract
Hippocampal circuits in the brain enable two distinct cognitive functions: the construction of spatial maps for navigation and the storage of sequential episodic memories. This dual role remains an enduring enigma. While there have been advances in modeling spatial representations in the hippocampus, we lack good models of its role in episodic memory. Here we present a neocortical-entorhinal-hippocampal network model that implements a high-capacity general associative memory, spatial memory, and...

Relationship Analysis
Both papers belong to the unified spatial-episodic memory architectures category, integrating spatial navigation and episodic memory within single computational frameworks. They overlap in addressing how sparse episodic memories can construct spatial world models, with both emphasizing the hippocampus's dual role in spatial and episodic processing. However, the original paper (ESWM) focuses on meta-learning from disjoint transitional memories using transformers for rapid adaptation and zero-shot navigation, while the candidate paper (Vector-HaSH) proposes a neocortical-entorhinal-hippocampal circuit model emphasizing factorized content storage, graceful capacity degradation, and one-shot memory via spatial scaffolds.

4. A unified model of spatial and episodic memory

Authors: Edmund T. Rolls, Simon M. Stringer, E. Rolls, Thomas Trappenberg, S. Stringer, et al. (9 authors total) | **Year/Venue**: 2002 | **URL**: View paper

Abstract
Medial temporal lobe structures including the hippocampus are implicated by separate investigations in both episodic memory and spatial function. We show that a single recurrent attractor network can store both the discrete memories that characterize episodic memory and the continuous representations that characterize physical space. Combining both types of representation in a single network is actually necessary if objects and where they are located in space must be stored. We thus show that ep...

Relationship Analysis
Both papers belong to the Unified Spatial-Episodic Memory Architectures category, proposing computational models that integrate spatial navigation and episodic memory within single frameworks. The original paper (ESWM) constructs spatial world models from sparse, disjoint episodic transitions using transformer-based architectures trained via meta-learning, enabling zero-shot generalization to novel environments. The candidate paper presents a theoretical attractor network model that stores both discrete episodic memories and continuous spatial representations, focusing on demonstrating how a single recurrent network can unify these two types of representations rather than learning from experience.

Contributions Analysis

Overall novelty summary. The paper introduces the Episodic Spatial World Model (ESWM), a framework that constructs spatial maps from sparse, disjoint episodic memories rather than long sequential trajectories. It resides in the 'Unified Spatial-Episodic Memory Architectures' leaf, which contains five papers total (including the original). This leaf sits within the broader 'Computational Models of Spatial and Episodic Memory' branch, indicating a moderately populated research direction focused on integrating spatial navigation and episodic memory within single computational frameworks. The taxonomy shows this is an active but not overcrowded area, with sibling papers exploring similar integration challenges using attractor networks and factorized representations.

The taxonomy reveals neighboring research directions that contextualize ESWM's position. Adjacent leaves include 'Episodic Memory Encoding and Retrieval Models' (three papers on temporal indexing and mental models) and 'Spatial Navigation and Cognitive Mapping

Models' (four papers on allocentric/egocentric representations). The exclude_note for the original leaf clarifies that models focusing exclusively on spatial or episodic aspects belong elsewhere, positioning ESWM as explicitly bridging both domains. Nearby AI Architectures branches explore reinforcement learning with episodic memory (four papers) and world models for sequential decision-making (three papers), suggesting ESWM connects computational modeling with practical AI implementation concerns.

Across three core contributions, the literature search examined thirty candidate papers total, finding zero refutable pairs. For the ESWM framework itself, ten candidates were examined with none providing clear refutation. Similarly, the geometric latent space contribution and zero-shot navigation capabilities each had ten candidates examined, again with no refutations identified. This suggests that among the limited top-thirty semantic matches explored, no prior work directly overlaps with ESWM's specific combination of sparse episodic integration, geometric alignment, and zero-shot task transfer. However, the modest search scope means more comprehensive surveys might reveal closer precedents in the broader literature.

Given the limited thirty-candidate search, ESWM appears to occupy a distinctive position within its moderately populated research area. The absence of refutations across all contributions, combined with the taxonomy showing only four sibling papers in the same leaf, suggests the work explores a relatively underexplored combination of episodic sparsity and spatial geometry. However, the analysis explicitly does not cover exhaustive literature review, and the taxonomy's fifty total papers indicate substantial related work exists across neighboring branches that may inform assessments of incremental versus transformative novelty.

This paper presents **3 main contributions**, each analyzed against relevant prior work:

Contribution 1: Episodic Spatial World Model (ESWM) framework

Description: The authors propose ESWM, a neural network framework that builds coherent spatial world models by integrating sparse, disjoint one-step transitions (episodic memories) rather than requiring long sequential trajectories. The model meta-learns to predict missing components of unseen transitions given a memory bank of disjoint experiences.

This contribution was assessed against **10 related papers** from the literature. Papers with potential prior art are analyzed in detail with textual evidence; others receive brief assessments.

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1. Towards qualitative spatiotemporal representations for episodic memory
URL: View paper

Brief Assessment

Qualitative Spatiotemporal Representations[62] focuses on qualitative spatial representations for episodic memory in strategy games using Hayes' histories framework, not on neural network-based world models that integrate sparse disjoint transitions for spatial reasoning and navigation.

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2. 3DLLM-Mem: Long-Term Spatial-Temporal Memory for Embodied 3D Large Language Model
URL: View paper

Brief Assessment

3DLLM-Mem[61] focuses on memory management for embodied LLM agents in 3D environments with working and episodic memory tokens for task execution, not on constructing spatial world models from sparse disjoint transitions through meta-learning as ESWM does.

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3. Hippocampal place cells, context, and episodic memory
URL: View paper

Brief Assessment

Place Cells Context[9] focuses on hippocampal place cells' role in context processing and episodic memory in biological systems, not on constructing computational spatial world models from sparse transitions. The paper examines neural mechanisms rather than proposing a meta-learning framework for artificial agents.

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4. High-capacity flexible hippocampal associative and episodic memory enabled by prestructured â□□spatialâ□□ representations
URL: View paper

Brief Assessment

Prestructured Spatial Representations[7] focuses on hippocampal associative and episodic memory mechanisms with prestructured spatial representations, not on constructing spatial world models from sparse disjoint transitions for navigation and planning tasks.

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5. Reinforcement learning and episodic memory in humans and animals: an integrative framework
URL: View paper

Brief Assessment

Integrative Framework[13] discusses episodic memory's role in RL at a theoretical/review level, focusing on how episodic memory can enhance value function approximation and learning efficiency. It does not propose a specific neural network architecture for constructing spatial world models from disjoint transitions, which is ESWM's core contribution.

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6. Breaking the chains: Toward a neural-level account of episodic memory.
URL: View paper

Brief Assessment

Breaking the Chains[45] focuses on temporal indexing mechanisms for episodic memory in immobile agents with dynamically changing scenes, not on constructing spatial world models from sparse disjoint transitions for navigation and planning tasks.

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7. World model as a graph: Learning latent landmarks for planning
URL: View paper

Brief Assessment

Latent Landmarks[64] focuses on learning graph-structured world models with sparse multi-step transitions for robotic planning tasks, not on constructing spatial maps from disjoint episodic memories as ESWM does. The candidate addresses planning over learned landmarks in continuous control domains, while ESWM addresses spatial world modeling from fragmented one-step transitions.

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8. Brain representations of space and time in episodic memory: A systematic review and meta-analysis
URL: View paper

Brief Assessment

Space Time Representations[63] is a neuroscience meta-analysis examining brain regions involved in spatial and temporal memory retrieval, not a computational framework for building world models from episodic memories. The candidate focuses on human brain imaging studies rather than neural network architectures.

9. Sleep Benefits Spatial Context Binding in Episodic Memory
URL: View paper

Brief Assessment

Sleep Benefits Binding[27] investigates how sleep consolidates episodic memory for spatial context associations in humans, not neural network frameworks for constructing spatial world models from disjoint transitions.

10. Space is a latent sequence: Structured sequence learning as a unified theory of representation in the hippocampus
URL: View paper

Brief Assessment

Structured Sequence Learning[65] focuses on hippocampal representations emerging from latent sequence learning principles, treating space as a sequence. The ORIGINAL paper proposes a neural network framework (ESWM) that constructs spatial maps from sparse disjoint episodic memories through meta-learning, which is architecturally and methodologically distinct.

Contribution 2: Geometric latent space reflecting environment topology

Description: ESWM's internal representations form a geometric map that mirrors the spatial layout of environments, including obstacles and boundaries. This structured latent space emerges without explicit supervision for spatial mapping and dynamically adapts when new memories are added or environmental structures change.

This contribution was assessed against **10 related papers** from the literature. Papers with potential prior art are analyzed in detail with textual evidence; others receive brief assessments.

1. Space is a latent sequence: A theory of the hippocampus
URL: View paper

Brief Assessment

Latent Sequence Theory[57] focuses on sequence learning in the hippocampus where spatial representations emerge from latent sequential structure, not on building geometric maps from sparse episodic memories that dynamically adapt to environmental changes like obstacles.

2. The role of latent representations for design space exploration of floorplans
URL: View paper

Brief Assessment

Design Space Exploration[52] focuses on floorplan design optimization using GRU-VAE latent representations of attributed graphs. The candidate does not address spatial world models, episodic memory integration, or dynamic adaptation to environmental changes that characterize ESWM's geometric latent space.

3. Toward Learning Latent-Variable Representations of Microstructures by Optimizing in Spatial Statistics Space
URL: View paper

Brief Assessment

Microstructure Representations[55] focuses on learning latent representations of material microstructures that preserve spatial statistics (texture-like properties), not on constructing geometric maps that mirror spatial layouts of navigable environments with obstacles and boundaries.

4. Physically reliable 3D styled shape generation via structure-aware topology optimization in unified latent space
URL: View paper

Brief Assessment

Structure-Aware Topology[56] focuses on encoding 3D shape geometry and structural relationships (part arrangements) for topology optimization in engineering design, not on spatial navigation or environment mapping. The latent space encodes component-level features for physical optimization, not spatial layouts for navigation tasks.

5. Place Cells as Proximity-Preserving Embeddings: From Multi-Scale Random Walk to Straight-Forward Path Planning
URL: View paper

Brief Assessment

The candidate paper context is too fragmented to assess whether it demonstrates prior work on geometric latent spaces that mirror spatial layouts. The provided excerpts mention 'topological structure of complex environments' but lack sufficient detail for meaningful comparison.

6. LaM-SLidE: Latent Space Modeling of Spatial Dynamical Systems via Linked Entities
URL: View paper

Brief Assessment

LaM-SLidE[60] focuses on latent space modeling for general spatial dynamical systems with entity tracking, not on cognitive maps or spatial navigation environments. The candidate does not address geometric alignment with environment topology or spatial layout in navigation contexts.

7. Latent representation learning for geospatial entities
URL: View paper

Brief Assessment

Geospatial Entity Representations[51] focuses on learning spatially-aware embeddings for geospatial entities (points, polylines, polygons) using graph neural networks with geodesic functions. This differs fundamentally from ESWM's contribution of emergent geometric latent spaces that mirror spatial layouts of navigable environments through episodic memory integration.

8. Disentangling the latent space of an end2end generative VRNN model for structural health condition diagnosis

URL: View paper

Brief Assessment

Disentangling Latent Space[53] focuses on structural health monitoring using VRNN models for condition diagnosis, not on spatial navigation or environment topology mapping. The latent space constraints mentioned relate to external loads and environment in a structural engineering context, not spatial layout.

9. GenCAD-Three-Dimensional: Computer-Aided Design Program Generation Using Multimodal Latent Space Alignment and Synthetic Dataset Balancing

URL: View paper

Brief Assessment

GenCAD-Three-Dimensional[59] focuses on CAD program generation using contrastive learning to align latent embeddings between CAD and geometric encoders for engineering design tasks. This is fundamentally different from ESWM's spatial world modeling from episodic memories for navigation and exploration in environments.

10. Living upon networks: A heterogeneous graph neural embedding integrating waterway and street systems for urban form understanding

URL: View paper

Brief Assessment

Heterogeneous Graph Embedding[54] focuses on urban form analysis by embedding street and waterway networks for predicting land surface temperature and housing prices. ESWM's contribution concerns spatial world models that dynamically construct geometric latent spaces mirroring environment topology (including obstacles and boundaries) from episodic memories for navigation tasks. These are fundamentally different application domains and technical approaches.

Contribution 3: Zero-shot exploration and navigation capabilities

Description: The learned world model supports near-optimal exploration and navigation in novel environments without task-specific training. ESWM can autonomously explore unfamiliar spaces and plan paths between arbitrary locations using only its learned ability to integrate episodic memories.

This contribution was assessed against **10 related papers** from the literature. Papers with potential prior art are analyzed in detail with textual evidence; others receive brief assessments.

1. X-mobility: End-to-end generalizable navigation via world modeling

URL: View paper

Brief Assessment

X-mobility[68] focuses on end-to-end navigation with world modeling for robotics in cluttered environments and sim2real transfer, while the original paper addresses autonomous exploration and navigation from episodic memories in novel environments without task-specific training. The technical approaches and problem domains differ substantially.

2. Exploration-Driven Generative Interactive Environments

URL: View paper

Brief Assessment

Generative Interactive Environments[75] focuses on training world models for environment simulation using exploration-driven data collection in virtual game environments, not on zero-shot exploration and navigation using learned world models in novel spatial environments as ESWM does.

3. Wild visual navigation: Fast traversability learning via pre-trained models and online self-supervision

URL: View paper

Brief Assessment

Wild Visual Navigation[70] focuses on visual traversability learning for robotic navigation in natural terrains using pre-trained models and online self-supervision. It does not address zero-shot exploration/navigation using learned world models from episodic memories without task-specific training, which is the core novelty of the original paper's ESWM framework.

4. Navigation world models

URL: View paper

Brief Assessment

Navigation World Models[66] focuses on video-based world models for navigation in robotics contexts, using diffusion transformers to predict future visual observations. The candidate does not address zero-shot exploration or navigation capabilities arising from episodic memory integration without task-specific training, which is the core novelty claim of the original paper.

5. Wmnav: Integrating vision-language models into world models for object goal navigation

URL: View paper

Brief Assessment

Wmnav[71] focuses on object goal navigation in indoor environments using VLMs, not on learning world models from episodic memories for general exploration and navigation as in the original paper.

6. Lm-nav: Robotic navigation with large pre-trained models of language, vision, and action

URL: View paper

Brief Assessment

Lm-nav[67] focuses on language-conditioned navigation using pre-trained models (LLM, VLM, VNM) to follow natural language instructions in outdoor environments. The original paper addresses zero-shot exploration and navigation using learned world models from episodic memories without language conditioning, representing a fundamentally different approach to the navigation problem.

7. Rapid exploration for open-world navigation with latent goal models

URL: View paper

Brief Assessment

Latent Goal Models[74] focuses on goal-conditioned navigation using learned distance models and topological memory in real-world robotic settings, rather than constructing spatial world models from episodic memories for zero-shot exploration as in the original paper.

8. ViNT: A foundation model for visual navigation
URL: View paper

Brief Assessment

ViNT[69] focuses on visual navigation using goal-reaching objectives with image observations, requiring pre-training on navigation datasets. The original paper's approach uses episodic memories and world models for exploration without task-specific training, representing a fundamentally different methodology.

9. Dino-wm: World models on pre-trained visual features enable zero-shot planning
URL: View paper

Brief Assessment

Dino-wm[73] focuses on zero-shot planning through action sequence optimization for goal achievement in visual environments, not on autonomous exploration and navigation using episodic memory integration as described in the original paper.

10. In-context reinforcement learning via communicative world models
URL: View paper

Brief Assessment

Communicative World Models[72] focuses on zero-shot adaptation through emergent communication protocols between two agents for task-solving in sparse-reward environments, not on autonomous exploration and navigation using episodic memory integration as in the original paper.

Appendix: Text Similarity Detection

No high-similarity text segments were detected across any compared papers.

References

- [0] Building spatial world models from sparse transitional episodic memories View paper
- [1] A non-Hebbian code for episodic memory View paper
- [2] Planning from imagination: Episodic simulation and episodic memory for vision-and-language navigation View paper
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- [31] Comparable human spatial memory distortions in physical, desktop virtual and immersive virtual environments View paper
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