REM-II: A Model of the Developmental Co-Evolution of Episodic Memory and Semantic Knowledge

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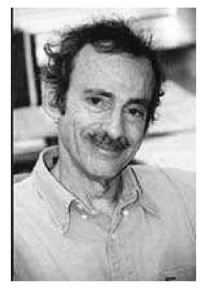
http://mypage.iu.edu/~stmuelle/MuellerShiffrinICDL2006.pdf

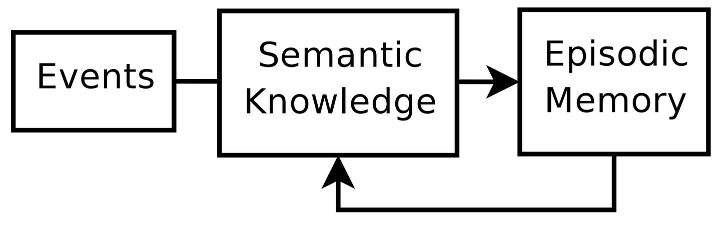


Abstract

Episodic memories are formed from the interpretation of events by semantic knowledge, while semantic knowledge is formed by the accumulation of episodic memories. Through this two-way process, our extensive episodic memory for events in the past co-evolves with our vast knowledge about the world. We present REM-II, a new bayesian account of episodic and semantic memory that explicitly models the development of these two aspects of our long-term memory. REM-II encodes episodic traces as sets of features with different values, and semantic knowledge as a set of co-occurrences of these features. The use of feature co-occurrence allows polysemy and connotation of meaning to be encoded within a single structure, and begins to approach the complexity of human knowledge. We demonstrate knowledge formation in REM-II and show the emergence of semantic spaces through experience and the resultant polysemy and biasing of encoding that REM-II produces.

Introduction

Objects and events and in the world are processed through the lens of human knowledge to form meaningful episodic memories. At the same time, these sparsely-coded yet durable memories accrue over time to form elaborate and deep knowledge about the world.



Despite the connections between these functionally distinct systems, they are typically studied in isolation, with few theories or models examining the relationship between the two.

REM-II: A Bayesian model of episodic memory and knowledge

1. Representation: Episodic traces are composed of features; knowledge encoded as feature co-occurrences.
2. Knowledge Encoding: Semantic knowledge is encoded as the co-occurrence of features in episodic traces.
3. Episodic Encoding: Episodic traces are formed by sampling from knowledge matrix in congruence with physical representations.
4. Memory Access: Memory structures have evolved to approximate bayesian probability computations.
5. Similarity/Differentiation: Semantic spaces grow because concepts appearing together share contextual features.

1. Representations of Knowledge

Episodic memory traces are sets of categorized feature counts.

Example Traces:

(red, small, round, sweet, yesterday, in kitchen,...)

(7,0,6,1,5)
or
(1,8,2,7,2)

Semantic Knowledge is accumulated as the co-occurrence of features in traces over experience.

Example Matrix

24	2	**22**	3	**23**
0	4	1	5	1
17	3	**22**	1	**18**
2	5	1	6	2
20	1	**17**	1	**22**

2. Knowledge Encoding

- Semantic knowledge is formed by accumulating feature co-occurrences from individual episodes.
- The episodic trace (1 0 1 0 1) forms the co-occurrence matrix.
- Each row in represents a biased encoding of a concept.
- Each cell represents a count of the number of co-occurrences of that pair of features in exemplars of the concept.

1	0	1	0	1
0	0	0	0	0
1	0	1	0	1
0	0	0	0	0
1	0	1	0	1

3. Encoding Episodic Traces

Episodes are encoded by:

1. Identifying appropriate knowledge matrix
2. Sampling row from matrix
3. Sampling feature from row
4. Repeat sampling process

Generic Encoding: Rows sampled based on accumulated features.
Biased Encoding: Rows sampled based on another set of features.

24	2	**22**	3	**23**
0	4	1	5	1
17	3	**22**	1	**18**
2	5	1	6	2
20	1	**17**	1	**22**

→ (7,0,6,1,5)
or
→ (1,8,2,7,2)

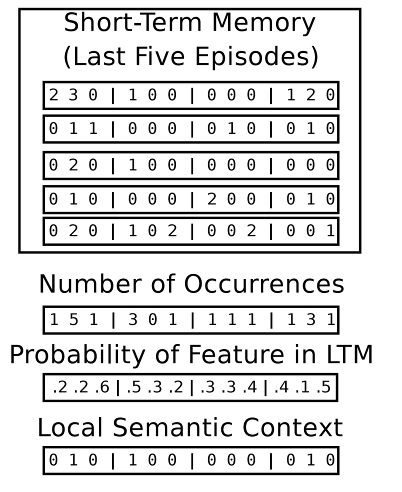
4. Memory Access

To access memory, a Bayesian calculation is performed simultaneously on all memory traces, computing the probability of each trace arising from a probe. For each feature category c and each feature f of a probe:

$$L_{match}(c,f) = \frac{c(p(c,f)) + (1-c)b(c,f)}{b(c,f)} \quad (1)$$

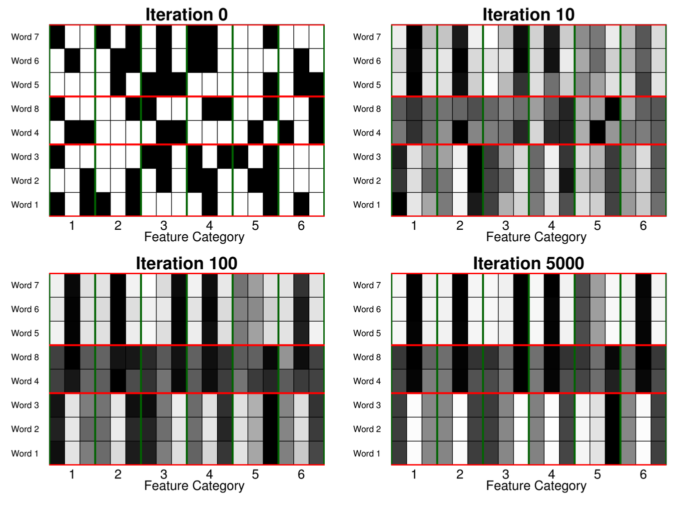
5. Similarity and Differentiation

- To generate a local semantic context, we examine recent episodes and find how frequently each feature occurred.
- We keep only those features that are unlikely to have arisen by chance.
- If concepts with different connotations exist, the knowledge matrix allows these multiple meanings to be encoded.
- Different meanings are supported by statistical regularities in the environment.
- We assume a hebbian process encodes the co-occurrence of features within a concept and between the concept and local context.



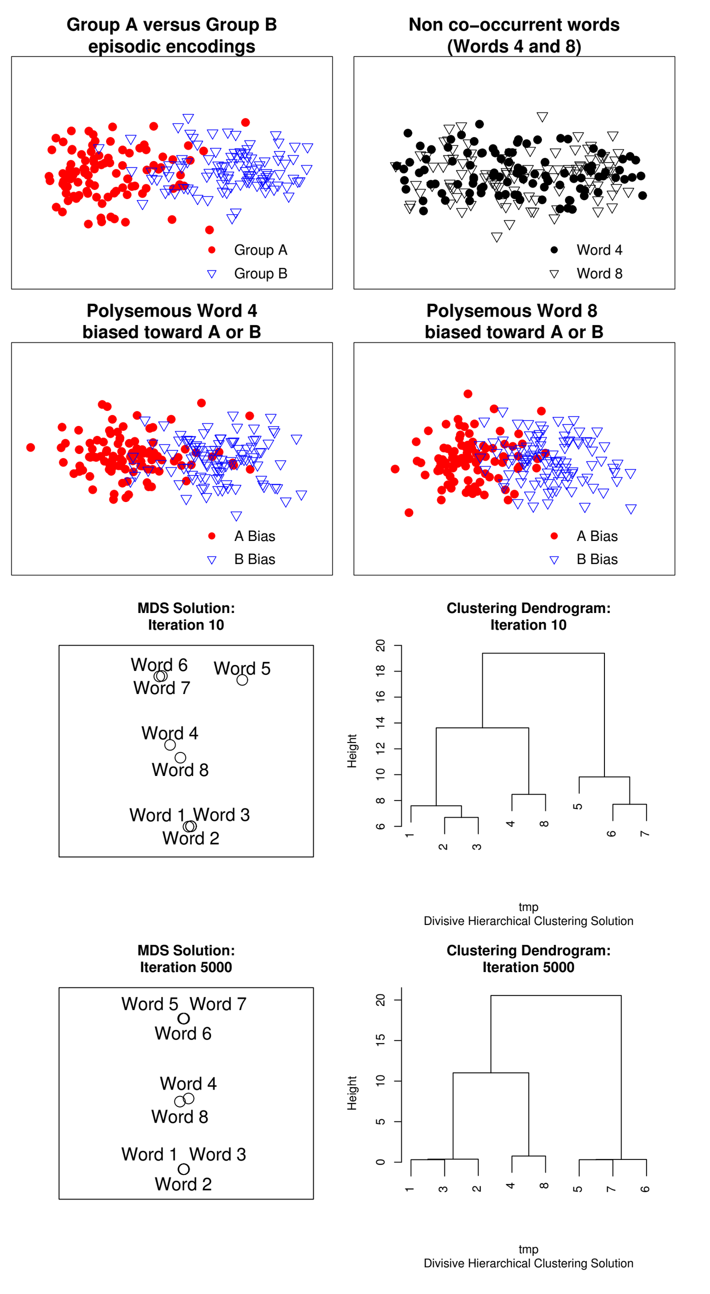
Simulation: Development of Polysemy

- When concepts appear in multiple contexts, different sub-meanings emerge in representation.
- Simulation involved two sets of items appearing separately (1-3 and 5-7); and two polysemous items appearing in both meaning groups (4 and 8).
- Results show episodes encoded from polysemous words can be biased toward one or another meaning group, allowing connations to be separate.



Simulation: Visualization of Semantic Space

- To visualize the semantic space produced by this process, we computed pairwise dissimilarity matrix for the knowledge traces representing each word.
- To compute dissimilarity from a matrix of feature co-occurrences, we divided each row of the matrix by the total number of counts in that row, so that each entry became a probability. We computed a sum squared difference between the probabilities in two matrices to get a total dissimilarity score between matrices.
- This dissimilarity matrix was then analyzed with the statistics software R using the multidimensional scaling function `isoMDS` from the `MASS` library, and the `diana` hierarchical clustering function from the `cluster` library.
- Resulting MDS and clustering analyses shown in figures on the right.



Discussion

- REM-II explicitly models the co-evolution of episodic memory and semantic knowledge.
- Hebbian processes sensitive to the statistics of the environment allow semantic spaces to form.
- Such a process predicts mirror frequency effects in recognition memory.
- Connotation and polysemy are represented in patterns of feature co-occurrence.
- Functional dissociations between episodic and semantic memory may represent two ends of a continuum, from weak individual episodes to strong, elaborated semantic knowledge.

Note

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