

## **A Monolithic Distributed Representation Supporting Multi-Scale Spatio-Temporal Pattern Recognition**

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An essential capability of the human cognitive system — *qua* pattern recognizer — is the on-line modulation of the level of responding as a function of instantaneous environmental contingencies. For example, in a typical conversation, a person may at one moment describe a very specific detail, i.e., so and so was wearing a blue flannel suit that day, and a moment later describe a more general fact, e.g., wearing such suits is typical of so and so. In general, such behavior indicates that humans:

- a) learn (embed) statistics of various orders — i.e., various levels (scales) of categorization
- b) can quickly vary the statistical level (i.e., representational level) on which the response depends most heavily.

Similarly, in the domain of automatic target recognition, we may be interested in finding all vehicles, or enemy vehicles, or all enemy vehicles posing an immediate threat in an image, and in weighting the instantaneous response more heavily on one of these levels of knowledge.

An important question is how knowledge (information) of different levels is represented in the brain. The space of models answering this question can be partitioned into three classes:

- A.) Those in which knowledge of different levels is represented disjointly — i.e., in physically separate representational structures.
- B.) Those in which all knowledge is stored in one monolithic structure that can be accessed at different levels of granularity as a function of various model parameters — e.g., thresholds.
- C.) Models utilizing both of the above principles.

The extant neurobiological evidence indicating a hierarchical organization of the brain in which representational (featural) level gradually increases from earlier cortices to later ones strongly suggests that the human brain utilizes principle A. In fact, a great many cognitive models utilize only this principle to explain the existence of various representational levels within the brain. However, the use of distributed representations offers another means by which higher-order statistical information can be represented. Specifically, the degree of overlap between two distributed representations,  $R(X)$  and  $R(Y)$ , can be used to encode the similarity of stimuli  $X$  and  $Y$ . In this case, the overlapping components constitute representations of the higher-order statistics — i.e., similarity structure — of the stimulus set,  $\{X, Y\}$ . This principle is demonstrated, for example, by the hierarchical clustering analyses that have been performed for various distributed neural models. What is needed is a mechanism that allows access of only the intersection of  $R(X)$  and  $R(Y)$  when output behavior reflecting only the higher order statistics is desired.

While the neurobiological evidence and the strong likelihood that the brain uses distributed representations together suggest that any complete cognitive model must exhibit both principles/mechanisms for representing higher-order knowledge, the research reported herein focuses on demonstrating only the latter principle (use of distributed representations) with respect to a particular neural network model of spatiotemporal pattern recall and recognition, TEMECOR (Temporal Episodic Memory using Combinatorial Representations). In particular, we provide simulation results showing that the model can learn the similarity structure — i.e., higher-order statistics — of a set of complex spatiotemporal feature patterns, even though these patterns are presented only once each. Additionally, the model retains traces of the specific spatiotemporal patterns as well. Thus, a single monolithic model demonstrates both episodic (specific) and semantic (general) memory capabilities. The level of access of the system — whether it be more toward the episodic (exemplar-specific) or more toward the semantic (category level) end of the spectrum can be controlled by the modulation of the threshold parameters.