Object categorization performance modeled using multidimensional scaling and category-consistent features

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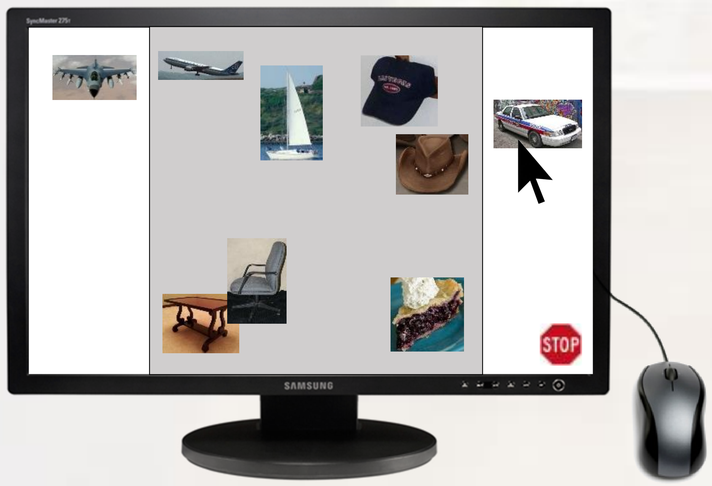
Understanding Categorization

- The ability to categorize is a crucial skill without which we would be unable to determine when two situations (or stimuli) are similar enough to be acted upon in the same way, or are dissimilar enough to warrant differential behavior.
- Yet, categorization typically happens so quickly as to seldom enter our consciousness.
- This work addresses the complex visual similarity relationships within and between categories that make possible this fundamental cognitive behavior.

- We're studying similarity relationships using two complementary approaches: 1) Multidimensional Scaling (MDS) data obtained from human observers (see Hout et al., 2012), and 2) Category-Consistent Features (CCFs), the important features of a target category, computationally defined as the high-frequency and low-variability features found across images of category exemplars (Yu, Maxfield, & Zelinsky, 2016).

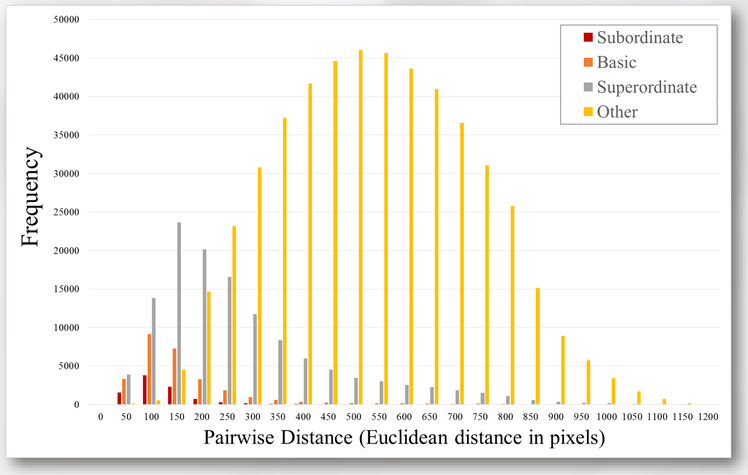
Similarity ratings (MDS)

- Participants provided similarity ratings for 144 objects (from 4 superordinate-level categories, each with 4 nested basic-level, and 3 nested subordinate categories).
- Similarity ratings were obtained using the *spatial arrangement method* (*SpAM;* Hout et al., 2013, 2016).
- 25 randomly selected items were first located outside a usable "arena." They were arranged on screen and placed at distances (relative to one another) that represented the observer's perception of similarity between each pair of items (closer in space denotes "more similar").
- Each participant completed 20 SpAM trials. There were 62 and 49 participants from NMSU and Stony Brook, respectively.



Multidimensional Scaling Results

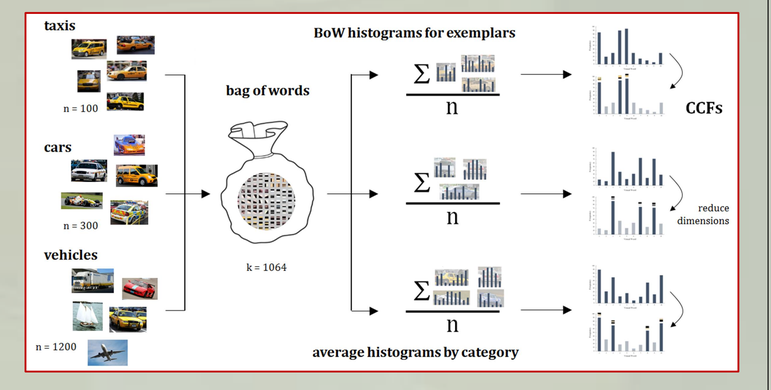
- Similarity ratings were subjected to an MDS analysis, along with scale- and participant-matched random Monte Carlo simulations.
- MDS is a data reduction technique that provides a spatial representation of the underlying relational structures contained in similarity data.
- The true data had significantly less stress than the simulated data.
- Importantly, the true data successfully recovered the subordinate-, basic-, and superordinate-level category clusters within our stimuli.
- Category "centroids" were then identified at each level of the hierarchy, representing the average X,Y,Z coordinates for a group of category members.

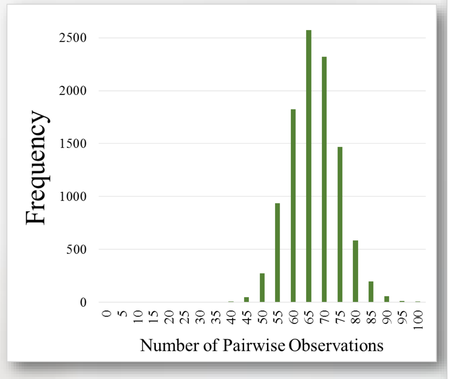


SpAM distances (Euclidean distance between two objects measured in pixels) presented for subordinate, basic, and superordinate "siblings," and for "other" pairs (i.e., members that shared no categorical overlap).

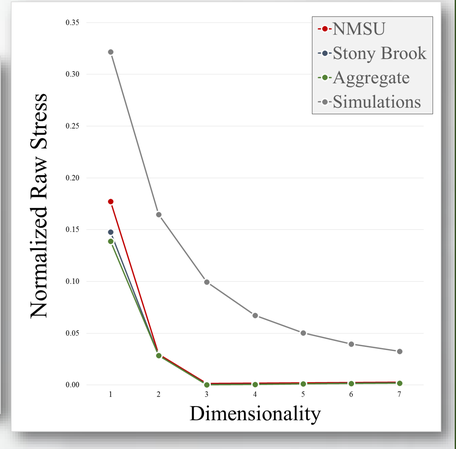
Category-Consistent Features (CCF) modelling:

An overview of the Category-Consistent Feature model. (i) SIFT and color histogram features are extracted from 100 exemplars for each of the 48 subordinate-level categories. (ii) Bag-of-Words is used to create a common 1064-dimensional feature space. (iii) BoW histograms were averaged by category; features (bins) in these averaged histograms now have a mean frequency and variability across exemplars. (iv) Features having low frequency and high variability are removed from the averaged histograms, leaving 68 histograms of CCF features.

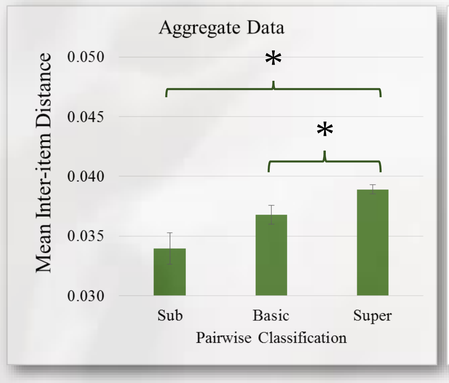


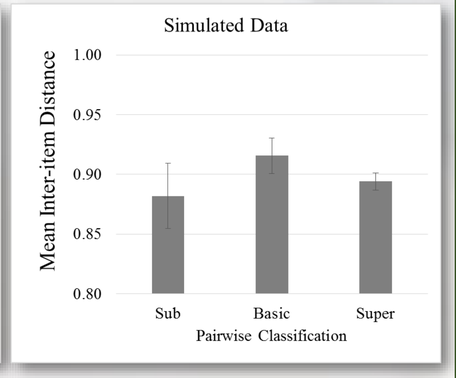


Number of times each possible pair of stimuli were randomly selected to co-occur in a SpAM trial.

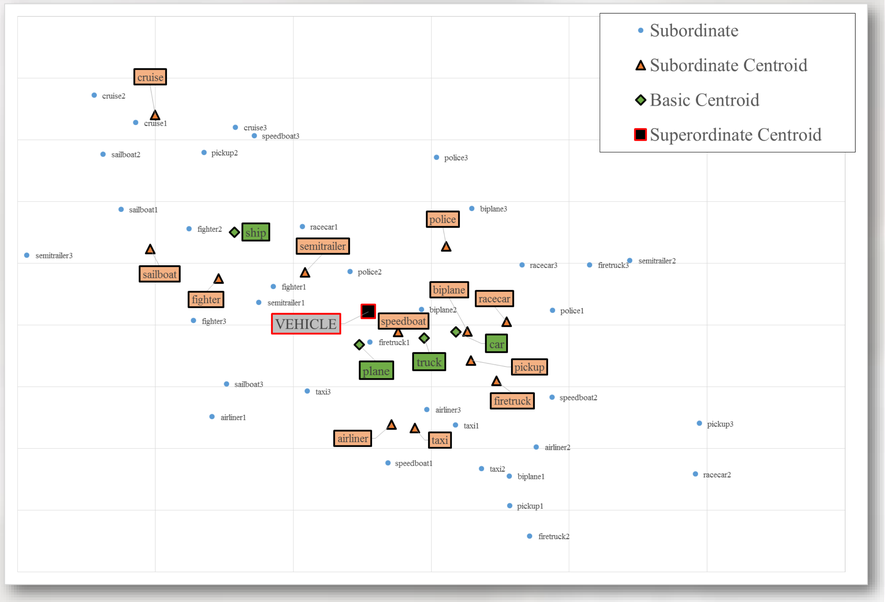


Scree plots showing stress as a function of dimensionality for data from each site, aggregated data, and simulated data. Multiple (10) simulations were conducted (the plot shows average stress across simulations).





MDS analysis successfully recovered the subordinate, basic, and superordinate level category relationships among our stimuli. Plotted here are distances in three-dimensional MDS space for each level of the hierarchy. Average distance for each exemplar to its subordinate "siblings" was smallest, followed by distances to basic-level and superordinate "siblings." No significant differences found between categories for simulated data.



Aggregate MDS solution (collapsed over two dimensions for simplicity) zoomed in on the superordinate vehicle category. Final placement of subordinate members are shown in blue dots. "Centroids" (i.e., center points for various members of the category hierarchy) are shown for the subordinate, basic, and superordinate level in orange triangles, green diamonds, and a black square, respectively.

- The CCF model is able to learn the most important visual features of an object category, analogous to the efficient feature representations that people use to guide behavior.
- Once CCFs are learned for range of categories, it will be possible to compute, from pixels, similarity distances between object categories and category exemplars, much like MDS does when computing distance to the category centroid.
- Future work will use both MDS and CCFs to predict performance on category verification tasks.