Compression in visual short-term memory: Using statistical regularities to form more efficient memory representations

Timothy F. Brady Talia Konkle George A. Alvarez

VSS '08

MIT BCS

Motivation

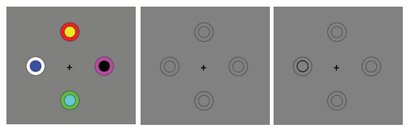
VSTM capacity is typically measured on displays where items appear in random locations, and estimates of capacity range from 3-4 colors and from 1 to 2 complex shapes (Luck & Vogel, 1997; Alvarez & Cavanagh, 2004).

However, in the world items do not appear randomly -- they tend to covary. This covariance should reduce the information needed to remember the displays (Shannon, 1948).

Can observers take advantage of statistical regularities to remember more colors in VSTM?

Exp. 1: Regularities in VSTM

Method: 8 AFC -> What color was the highlighted circle?

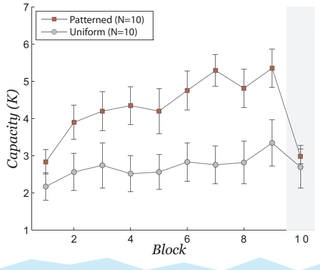


Patterned group color pair statistics:

80% of probability mass

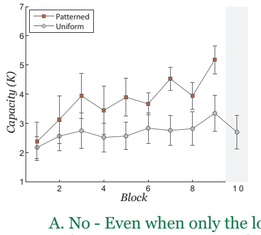
20% of probability mass

In block 10, the displays became uniformly distributed for the patterned group



Observers remember more colors when the pairs they appear in are predictable

Q. Are observers just remembering a few colors and guessing the rest using the regularities?

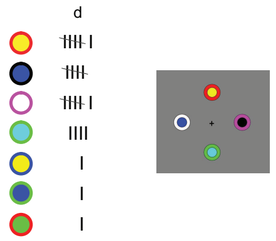


A. No - Even when only the low frequncy pairs are considered, capacity improves over time.

Information Theoretic Model

-> Bayesian Model of Learning

Tallies observed color pairs to estimate the probability of seeing each pair



$\theta \sim Dirichlet(\alpha)$

$d \sim Multinomial(\theta)$

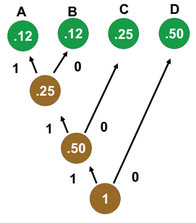
- d is the observed color pairs
- α is the prior on how strongly observers believe color pairs will be drawn uniformly
- We wish to estimate the posterior on θ, p(θ | d, α)

-> Huffman Coding Model

Uses probabilities from the learning model to encode the stimuli efficiently

	Standard Code	Huffman Code
Θ_1= 0.22	000000	011
Θ_2= 0.20	000001	100
Θ_3= 0.21	000010	010
Θ_4= 0.04	000011	0001000
...		
Θ_{64}= 0.05	111111	0001111

Huffman Coding Example:

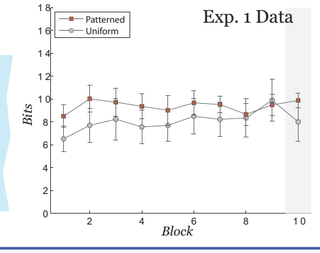


A = 111
B = 110
C = 10
D = 0

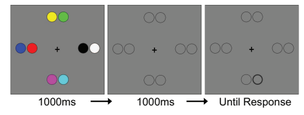
-> Model Results

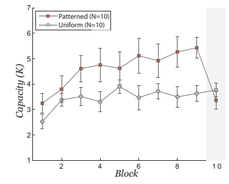
The number of bits required to match observers' performance in each block, based on the coding model

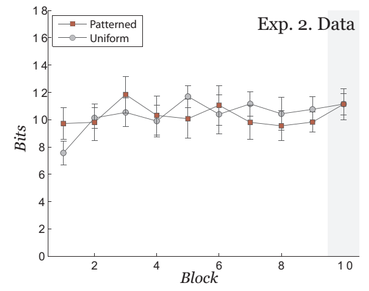
Memory capacity is constant in the number of bits remembered, rather than the number of colors.



Exp. 2: Regularities Between Objects







Observers use regularities between objects as well as within objects. Memory capacity is still constant in bits.

Discussion

- Observers remember more colors when they can rely on statistical regularities.

- This VSTM capacity is consistent with a fixed capacity in bits rather than in terms of number of objects.

The data are also consistent with a model of VSTM capacity in terms of a fixed number of 'chunks', where frequently associated colors get put into a single slot.

However, such a model is simply an all-or-nothing approximation to the compression algorithm described here.

Alvarez, G. A., & Cavanagh, P. (2004). The capacity of visual short-term memory is set both by visual information load and by number of objects. *Psychological Science*, 15, 106-111.

Luck, S.J., & Vogel, E.K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, 390, 279–281.

Shannon, C.E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, 27, 379–423.