Measuring Visual Mechanism Sensitivity

Charles Chubb, UC Irvine
Michael S. Landy, NYU

The search for the grail
(the underlying mechanisms of preattentive vision)

- If your visual system spontaneously discriminates two textures, this means your brain has at least one preattentive mechanism that is more activated by one of the two textures than the other.
- How many such mechanisms exist in human vision, and what do they sense?

So what are the mechanisms?

- Feature maps? (from search experiments)
- Texton-detectors? (Julesz, 1980,1981; Julesz & Bergen, 1983)
- Complex cells?
- ~~On- and off-channel simple cells~~?

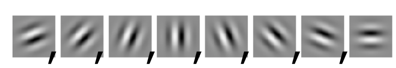
Motoyoshi & Kingdom (in press)

A way to make progress

Take a set of micropatterns (e.g.,

or

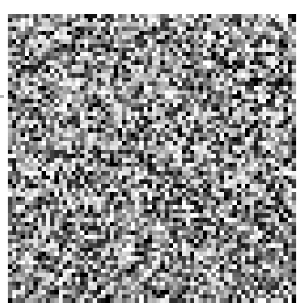
or



--or whatever)

Scrambles

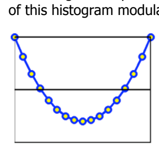
Randomly arranged textures with precisely controlled histograms

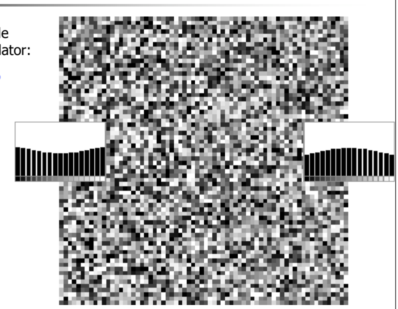


The uniform histogram:

Histogram perturbations

Increasing the amplitude of this histogram modulator:





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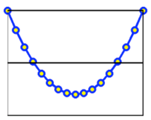

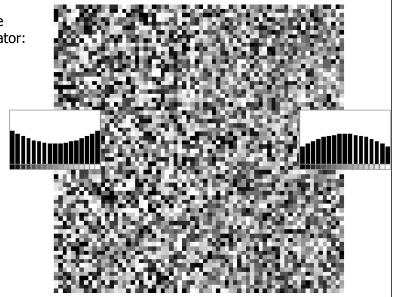

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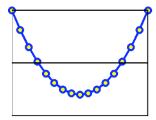

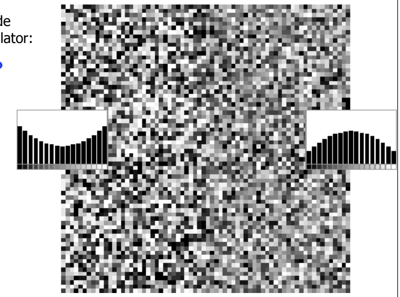

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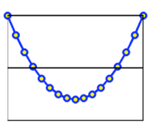

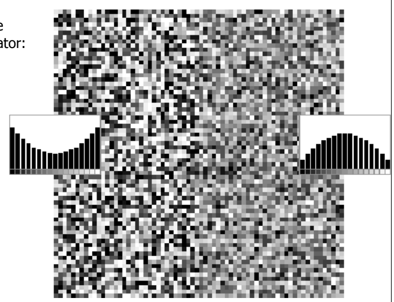

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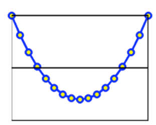

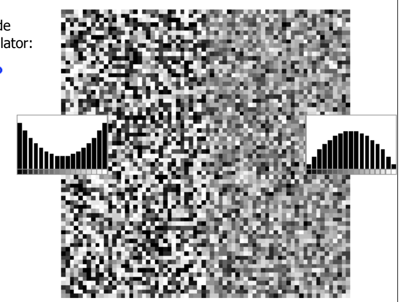

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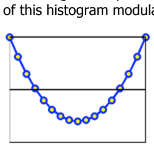
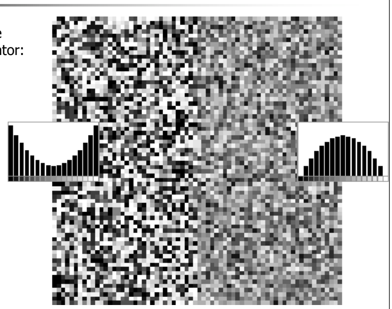
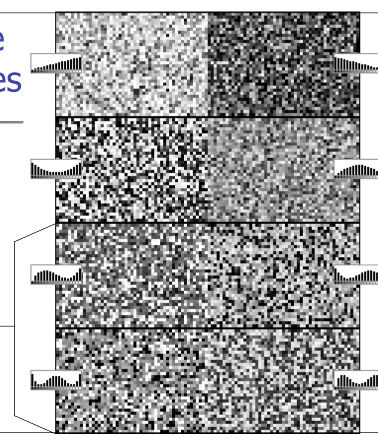




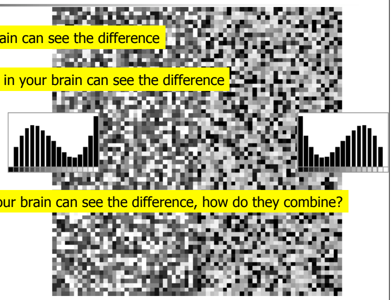
Scramble Species



Only one mechanism
is sensitive to the
differences between
these four scrambles.

So how do you discriminate two scrambles?

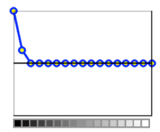
1. Something in your brain can see the difference
2. Maybe several things in your brain can see the difference

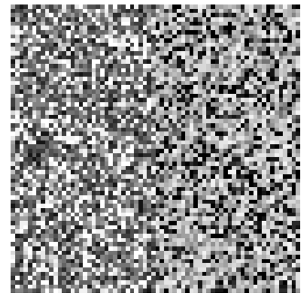


3. If several things in your brain can see the difference, how do they combine?

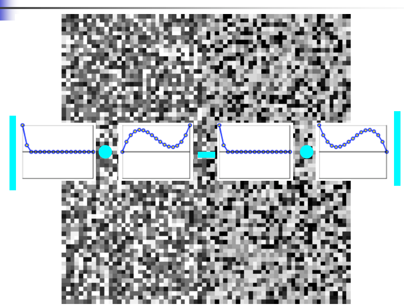
Scrambles and the single mechanism

Blackshot sensitivity function:





Scrambles and the single mechanism



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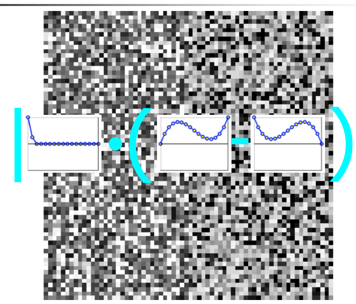
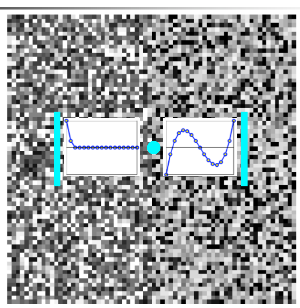


Scrambles and the single mechanism



So this means

If a mechanism has sensitivity function *f*, then the discrimination strength generated in that mechanism by a modulator ϕ is

$$\text{discrimination strength} = |f \bullet \phi|$$

Scrambles & many mechanisms

- Suppose we have N different mechanisms with sensitivity functions $f_1, f_2, \ldots, f_N$
- Then a modulator ϕ generates discrimination strengths

$$|f_1 \bullet \phi|, |f_2 \bullet \phi|, \ldots, |f_N \bullet \phi|$$

How do these discrimination strengths combine?

Minkowski combination

Usual assumption: for some $\gamma \geq 1$

$$Discriminability(\phi) = \left(\left|f_1 \bullet \phi\right|^{\gamma} + \left|f_2 \bullet \phi\right|^{\gamma} + \ldots + \left|f_N \bullet \phi\right|^{\gamma} \right)^{\frac{1}{\gamma}}$$

Note: if $\gamma = 2$, then $Discriminability(\phi)$ is the Euclidean length of the vector $(f_1 \bullet \phi, f_2 \bullet \phi, \ldots, f_N \bullet \phi)$

= $F\phi$ for F the matrix of sensitivity functions.

The nonuniqueness problem

(Poirson, Wandell, Varner & Brainard, 1990)

- In practice, we can't reject $\gamma = 2$.
- However, if $\gamma = 2$, then $Discriminability(\phi) = |F\phi|$ for F the matrix of sensitivity functions.
- Hence, $Discriminability(\phi) = |RF\phi|$ for any rotation R.

The Bummer Conclusion: ***we can't determine individual sensitivity functions!***

Getting around the problem

- ***SEPARABILITY***--Poirson & Wandell, 1993, 1996: introduce a second stimulus parameter (spatial frequency of the pattern alternating between scrambles) and assume that across different spatial frequencies, sensitivity functions may change in relative amplitude but not in their forms. This lets one derive the sensitivity functions.
- Pro: broad applicability
- Cons:
  - Lots of parameters make this model hard to reject
  - Lots of data needed for reasonable estimates of sensitivity functions

Getting around the problem

- ***UNIVARIANCE***--Chubb, Econopouly, Landy, 1994; Chubb, Landy, Econopouly, 2004: if one can hypothesize and confirm that only one mechanism is sensitive to differences between scrambles in a given subspace of modulators, one can determine the sensitivity function of that mechanism.
- Pro: enables precise measurement of sensitivity function
- Con: only applicable in special circumstances

The "no peeking" problem

- Suppose you know the space spanned by your mechanism sensitivity functions.
- A space of modulators is univariate if and only if it projects to a 1-D subspace of this space.
- Which means: you can no longer hypothesize that a given space is univariate. **Therefore**, you can't use the univariance strategy.

A final scramble suggestion

- Choose the number of micropatterns in your scrambles carefully--see, e.g. Bonin, Mante, Carandini, 2006.
  - The fewer you use, the more power you have in estimating the influence each exerts on performance.
  - BUT you should probably use several more than the number of mechanisms you think may exist (to enable the discovery of multidimensional, univariate subspaces).