The Function and Fallibility of Feature Integration: A Dynamic Neural Field Model of Illusory Conjunctions

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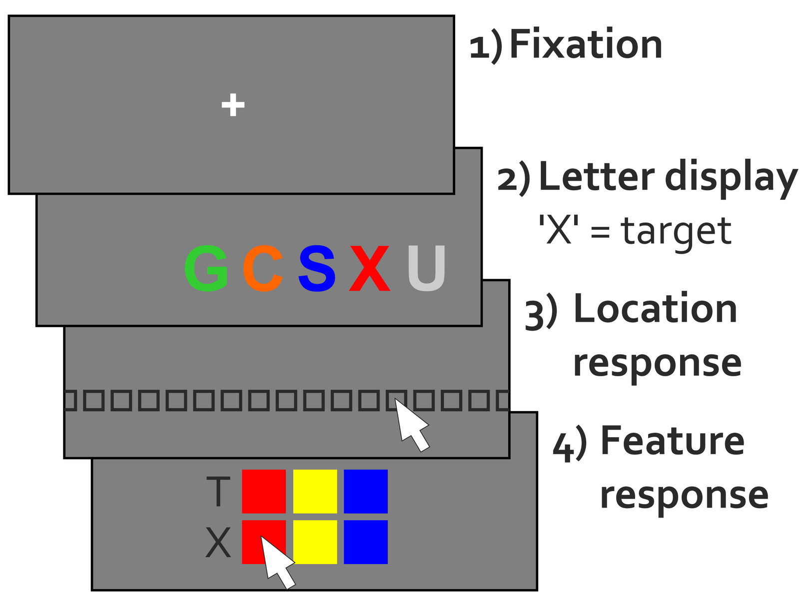
1. Introduction

Illusory conjunctions (ICs) are failures of feature integration where features of distinct objects are combined into one percept [1]. For example, subjects presented with a blue 'S' and a red 'X' sometimes report having seen a blue 'X'.

ICs in vision are more likely to occur between spatially close items [2], and between items having similar features [3]. Furthermore, the illusory percept tends to be located at the spatial midpoint between the involved items [4]. These findings set constraints on possible mechanisms of visual feature integration.

Here, we present a neurodynamic model of visual feature integration that captures this evidence. To test the model, we subjected it to a task similar to that used in [4] (see figure).

(letter identity 'X' or 'T' specifies target)

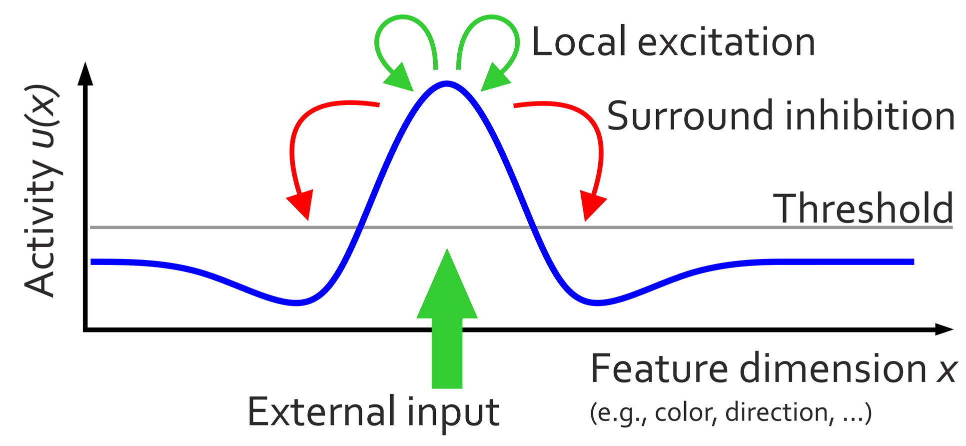


2. Dynamic Neural Fields

Dynamic Neural Fields (DNFs) describe neural activity patterns within cell populations as continuous distributions of activation over metric feature dimensions [5,6]. The continuous evolution of activity is governed by external inputs and lateral interactions within the DNF. The interactions promote the formation of localized peaks of activity, which serve as units of representation. Peaks may reflect:

- **Perceptual items**, such as features or spatial locations.
- **Memory items**, in the form of self-sustained peaks.
- **Motor parameters** of upcoming actions.

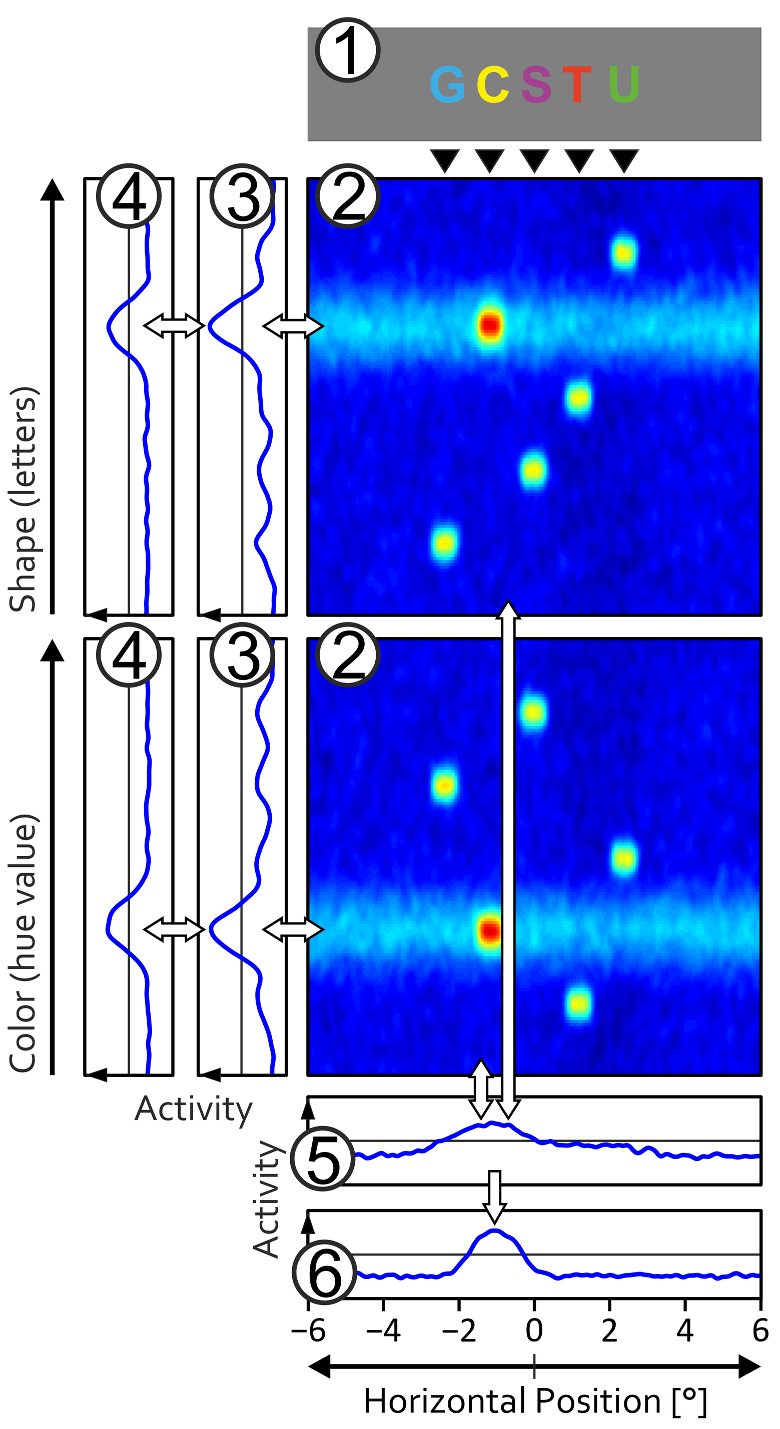
Selection between competing percepts or actions may be forced by local or global inhibition.



$$\tau\dot{u}(x) = -u(x) + h + s(x) + \int w(x-x')f(u(x'))dx'$$

3. Architecture

The model consists of a feature pathway and a spatial pathway, which interact through two shared low-level visual representations in a retinal frame. The feature pathway comprises two analogous layers, one for color and one for shape, which are linked solely via a spatial attention field.



① **Visual scene (1D visual space)**
Input to the visual perception fields.

② **Visual perception fields (2D)**
Peaks indicate the combination of shape and location (top) and color and location (bottom) for each perceptual item.

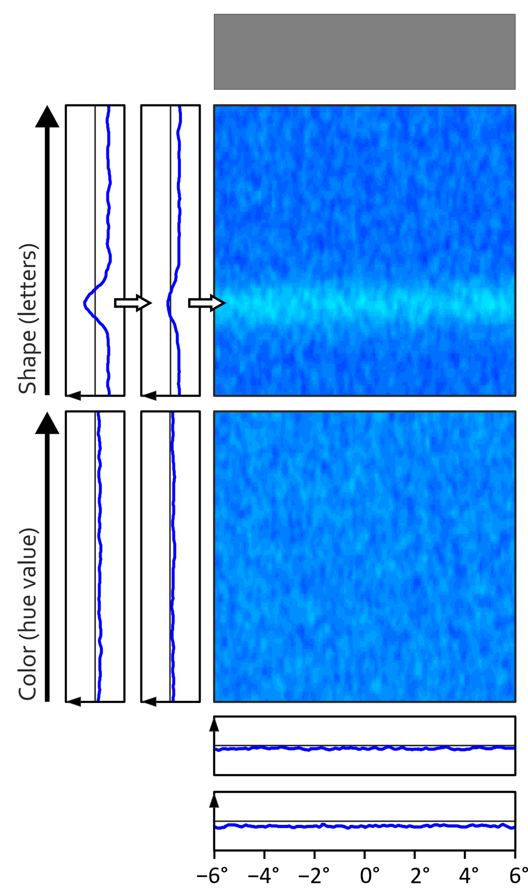
③ **Feature attention fields**
Reflect stimulus shape/color independent of location and modulate visual perception. Each field allows a single peak, thus implementing attentional competition between different feature values.

④ **Feature memory fields**
Retain a target feature or allow the read-out of a feature value as feature response. Each field allows a single self-sustained peak.

⑤ **Spatial attention field**
Allows a single peak. Implements competition between stimulated spatial locations and biases activity in the visual perception fields.

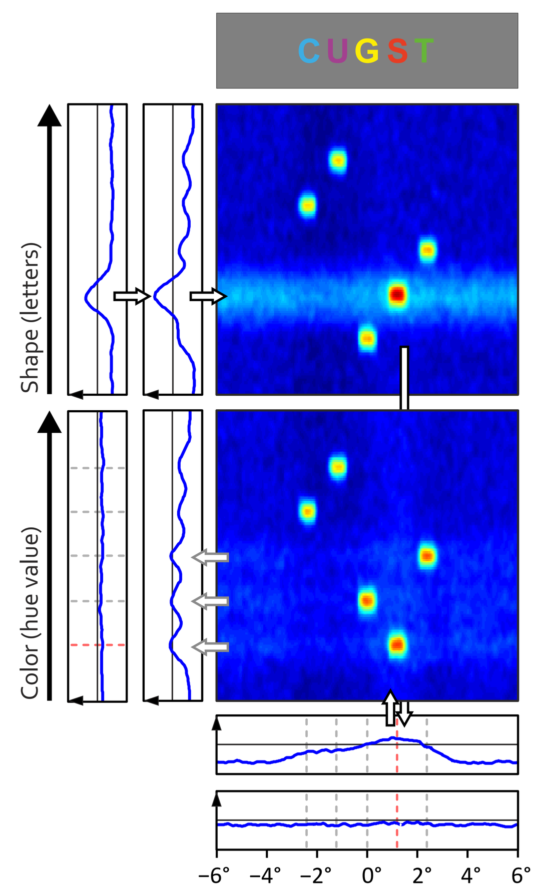
⑥ **Spatial read-out/ motor field**
Allows a single self-sustained peak. Reads out spatial location to guide a motor response.

4. Simulation



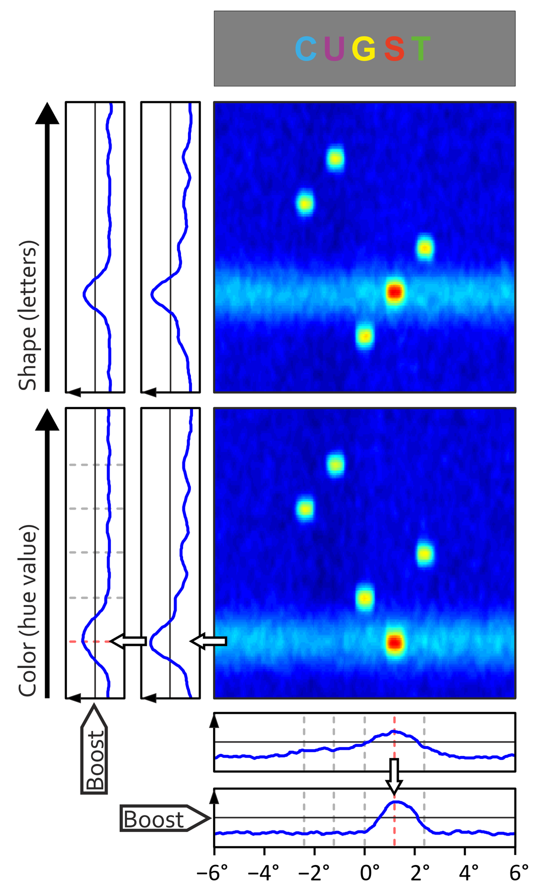
I. Pre-stimulus Phase

At the start of each trial, a cue item is presented (not shown), and the shape memory field is forced to build a peak by briefly boosting its resting level. The peak reflects the target shape and persists throughout the trial, causing an activity bias in favor of the target shape in the feature attention field and, consequently, the visual perception field.



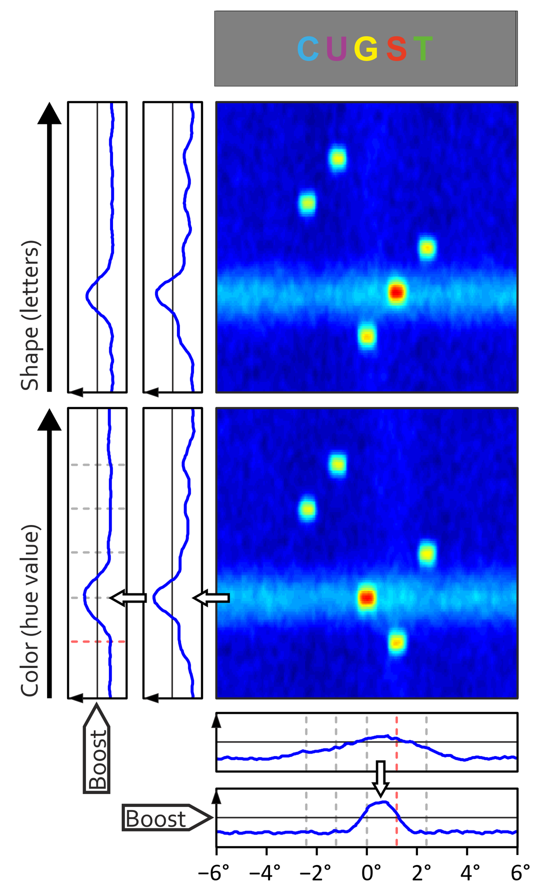
II. Stimulus Display

For each item, a peak arises in each visual perception field. The preactivation enhances the target item´s shape peak, which projects to the corresponding location in the spatial attention field. In turn, the spatial attention field activates this region in the visual perception field for color. Peaks close to the center of this region are more strongly enhanced than distant ones.



IIIa. Correct Response

Since it shares a spatial location with the shape peak, the target item´s color peak is most strongly enhanced. It therefore prevails in determining the peak position in the color attention field. Next, the color memory field and the spatial read out field are boosted, forcing them to build peaks which correctly indicate color and location of the target item.



IIIb. Illusory Conjunction

In some cases, however, the coarseness of the projections to and from the attention fields leads to non-target peaks being overly enhanced. The spatial attention peak then deviates towards the respective distractor, as it is jointly determined by two peaks at different spatial locations. Ultimately, a distractor color may be selected – an IC occurs.

5. Results

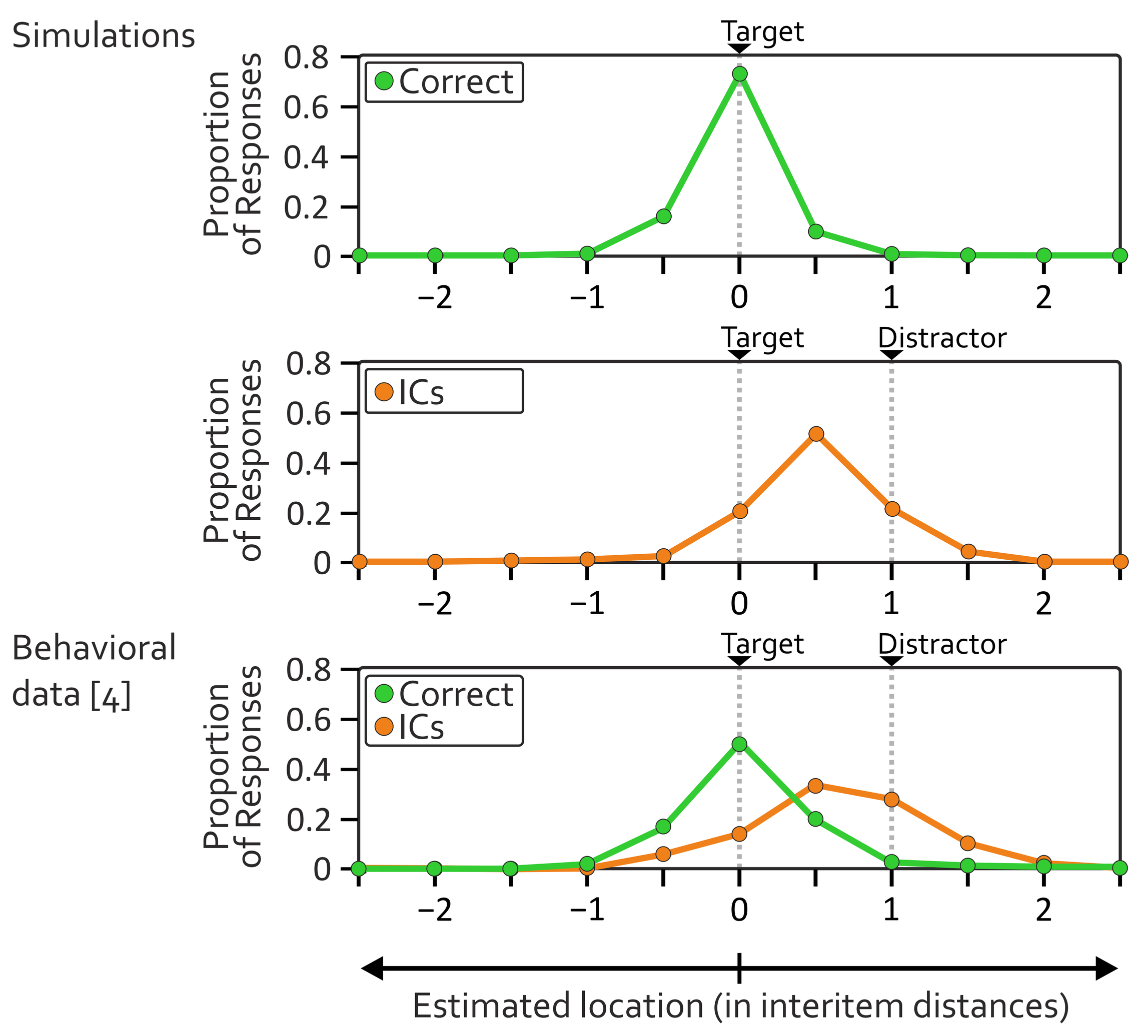
Response proportions accord well with those reported in [4] (see table) and are generally consistent with the behavioral evidence. As in [4], only the middle three stimuli were included in the analyses. Figures show data for ICs between adjacent items.

	% Correct responses	% ICs across 1 position	% ICs across 2 positions
Model	87.12	11.68	1.20
Experiment [4]	83.96[1]/91.82[2]	12.92[1]	4.35[2]

[1] of all trials where the distractor was adjacent to the target.
[2] of all trials with an intermediate letter between target and distracter.

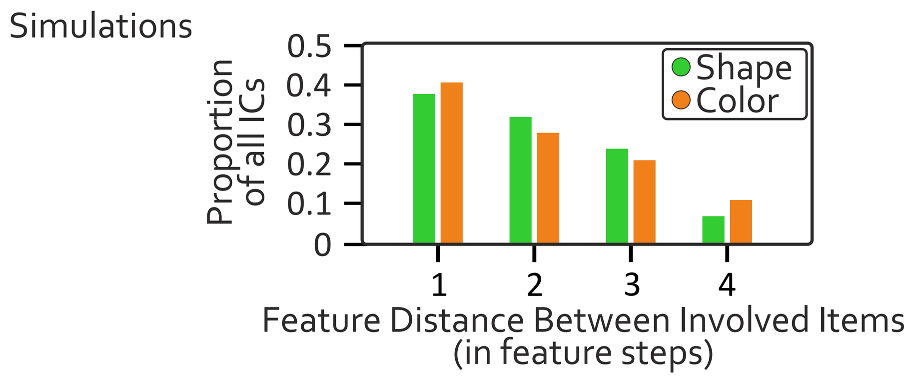
Spatial Locations

Consistent with [4], the model tends to localize ICs halfway between the target and the involved distractor, while estimates for correct responses are distributed around the target location.



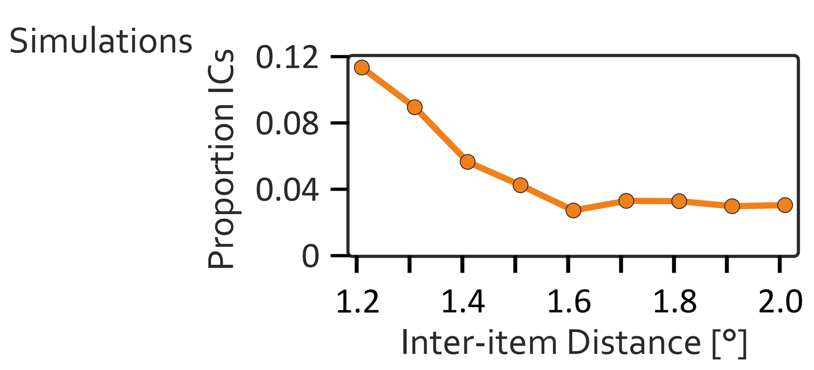
Effect of Feature Similarity

Consistent with [3], ICs occur more often between items with similar feature values. The model predicts similarity effects for both the target-defining and the reported dimension.



Effect of Spatial Distance

The likelihood of ICs decreases with increasing inter-item distance, as expected from findings such as [2].



6. Conclusion

Our neurodynamic model can account for several key effects reported in the behavioral literature. Namely, IC formation depends on the distance of items in both physical and feature space, and ICs are spatially localized halfway between the involved items. The model describes how visual features may be integrated into coherent objects by dynamically interacting neural representations of low-level inputs, feature information, and physical space. It further provides an explicit neural mechanism for the formation of ICs, based on the coarse nature of spatial and featural selection mechanisms. The model thus complements existing theories that attribute ICs to spatial uncertainty during feature registration rather than selection [7]. Our conceptions, particularly that of a shared spatial frame as the basis for visual feature integration, are supported by the parallels with the behavioral literature.

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