Neural Networks 37 (2013) 93–102

Contents lists available at SciVerse ScienceDirect

Neural Networks

journal homepage: www.elsevier.com/locate/neunet

DISCOV (DImensionless Shunting COlor Vision): A neural model for spatial data analysis

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ARTICLE INFO

Keywords:
Color vision
Opponent processing
Single opponent
Double opponent
Spatial analysis
Remote sensing

ABSTRACT

The DISCOV (DImensionless Shunting COlor Vision) system models a cascade of primate color vision neurons: retinal ganglion, thalamic single opponent, and cortical double opponent. A unified model derived from psychophysical axioms produces transparent network dynamics and principled parameter settings. DISCOV fits an array of physiological data for each cell type, and makes testable experimental predictions. Binary DISCOV augments an earlier version of the model to achieve stable computations for spatial data analysis. The model is described in terms of *RGB* images, but inputs may consist of any number of spatially defined components. System dynamics are derived using algebraic computations, and robust parameter ranges that meet experimental data are fully specified. Assuming default values, the only free parameter for the user to specify is the spatial scale. Multi-scale analysis accommodates items of various sizes and perspective. Image inputs are first processed by complement coding, which produces an ON channel stream and an OFF channel stream for each component. Subsequent computations are on-center/off-surround, with the OFF channel replacing the off-center/on-surround fields of other models. Together with an orientation filter, DISCOV provides feature input vectors for an integrated recognition system. The development of DISCOV models is being carried out in the context of a large–scale research program that is integrating cognitive and neural systems derived from analyses of vision and recognition to produce both biological models and technological applications.

1. Introduction

Black-and-white movies and colorblind individuals convince us that we could successfully navigate a grayscale world, that color signals are, for the most part, not essential for recognition. The Flowers image (Fig. 1a), compared with the same image in grayscale (Fig. 1b, center rectangle), shows how color may carry essential information in natural images. More generally, a host of datasets from sources such as satellites, business, and social networks carry spatially organized information that cannot be reduced to a single dimension.

The DISCOV (DImensionless Shunting COlor Vision) model transforms red–green–blue (*RGB*) image components into a cascade of retinal, single opponent, and double opponent features that serve as inputs to a recognition system. The Flowers image illustrates model computations in terms of an *RGB* photograph, but *RGB* could equally well stand for combinations of other spatial inputs, such as UV, IR, demographic data, or geographic features, or feature combinations such as principal components. The model accommodates any number of spatially defined input components in pairwise computations.

All DISCOV model dynamics are derived from straightforward algebraic computations. The only parameter that the user need specify is the general size of items of interest for the target problem. Fig. 1a illustrates four spatial scales corresponding to near-to-far perspective. In a remote sensing application, multiple spatial scales may accommodate objects of widely varying sizes. Reflecting the biological and technological interpretations of DISCOV, the term *node* is used interchangeably with *neuron* or *pixel*.

An early version of DISCOV (Chelian & Carpenter, 2005) shows how the model, using a small set of shared parameters, matches a broad array of experimental data for retinal, single opponent, and two types of double opponent cells (e.g., Enroth-Cugell and Robson (1984), Livingstone and Hubel (1984), Reid and Shapley (2002), and T'so and Gilbert (1988)). This paper compared DISCOV with the Neural Fusion software module (Ross et al., 2000), which also features computations called retinal, single opponent, and double opponent. However, Neural Fusion results did not match many of the experimental observations, with its "double opponent" outputs nearly identical to those of its single opponent outputs.

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doi:10.1016/j.neunet.2012.08.012

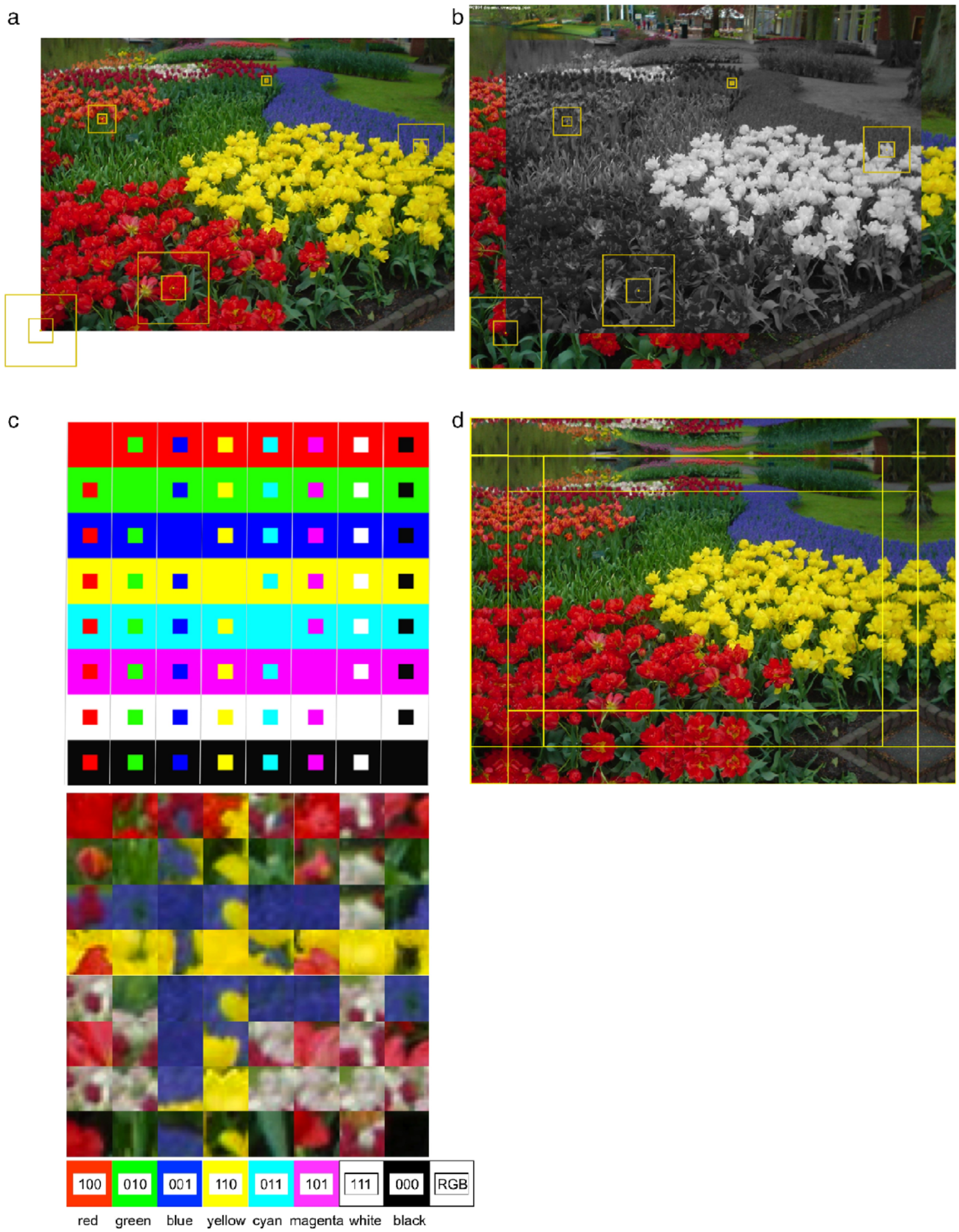

Fig. 1. Images that illustrate DISCOV model computations. (a) The Flowers image (480 × 680 pixels). Yellow squares indicate patch kernels at four spatial scales (15, 45, 75, and 117 pixels across). Parameter α denotes the number of pixels in the center square, and the area of each surround square is nine times the area of its center square ($A = 9$). (b) The central rectangle shows the Flowers image in grayscale, surrounded by a fringe from the full Keukenhof image, which is 600 × 800 pixels. DISCOV computations near an image boundary use pixel values from such a fringe. The minimum fringe size depends upon the largest spatial scale of interest: the patch kernel in the lower left ($\sqrt{A\alpha} = 117$ pixels across) is the largest one that fits into the fringe, which is 60 pixels wide. (c) Image patches with binary *RGB* center and surround colors, and patches from the Flowers image that are closest to their binary counterparts. Patches are magnified by a factor of 5 (across) from the Flowers image. In each patch, the center square is $\sqrt{\alpha} = 5$ pixels across and the surround square is $\sqrt{A\alpha} = 15$ pixels across, at the smallest spatial scale of the patches in (a). (d) A fringe may be constructed by reflecting nearby image strips. Here, strips 60 pixels wide are reflected across the four edges of the Flowers image, and 60 × 60 pixel squares are further reflected at each corner. Strips are constructed to enclose the DISCOV patch at the largest spatial scale of interest.
Source: Keukenhof photo source: http://dreams.smugmug.com/gallery/109012_29Psn#3872656_XPFQR