CN530, Spring 2004

Boundary Gated Diffusion.

Madhu Shashanka

shashanka@cns.bu.edu

2 March 2004

Abstract

Computer simulations of a neural network model of 1-D and 2-D brightness phenomena developed by Grossberg and Todorović (see [1]) are presented. The model is comprised of network interactions between a Boundary Contour System (BCS) and a Feature Contour System (FCS). The model correctly predicts actual brightness percepts for simulated phenomena. Simulated phenomena include the Craik-O'Brein-Cornsweet effect in 1-D and 2-D, and Koffka-Benussi ring in 2-D.

Introduction

The aim of this assignment is to model some of the classical phenomena associated with achromatic brightness perception. We implement the neural network model developed by Grossberg and Todorović [1] and simulate these phenomena.

Model Background

The model is a hierarchy of spatially organized network interactions. These levels form two parallel contour-sensitive systems called the Boundary Contour System (BCS) and the Feature Contour System (FCS). The BCS synthesizes an emergent binocular boundary segmentation from combinations of oriented and unoriented scenic elements. The FCS triggers a diffusive filling-in of featural quality within perceptual domains whose boundaries are determined by output signals from the BC system. We use a single-scale monocular version of the model as described in [1]. There are six levels of the model and their brief descriptions are as follows:

- The first level of the model consists of a set of units that sample the luminance distribution.
- Level 2 models cells with the type of circular concentric receptive fields found at

early levels of the visual system.

- Level 3 consists of cell units that share properties with cortical simple cells. They are sensitive to oriented luminance contrasts in a specific direction-of-contrast.
- Level 4 units model cells sensitive to contrasts of specific orientation regardless of contrast polarity. Level 4 unit at a particular location is excited by two Level 3 units at the corresponding location having the same axis of orientation but opposite direction preference.
- Signals sensitive to different orientations are pooled in at level 5.
- Level 6 is where "filling-in" takes place and activity here corresponds to the brightness percept. The units in this level can be thought of as a syncytium of cells where activities rapidly spread to neighbors and "filling-in" occurs. Boundaries formed by the BCS act as barriers for this "diffusion".

Simulation details

A detailed mathematical description of the model can be found in the appendix of [1]. For all the simulations that follow, we use the parameters as given in [1]. Items 1 through 5 discuss 1-D simulations and item 6 deals with 2-D simulations. All 1-D simulations involved 256 units. In the case of 2-D simulations, the COCE simulation used 30×30 units while the Koffka-Benussi ring simulation involved 40×40 units. All differential equations involved (except Level 6) were solved for equilibrium. The nonlinear diffusion equation describing Level 6 was solved using the ODE solver `ode23s` of MATLAB. This command helps one to solve stiff-differential equations and uses the rosenbrock method for solving.

For 1-D simulations, we plot the outputs of Level 1 (`STIMULUS`), Level 2 (`FEATURE`), Level 5 (`BOUNDARY`) and Level 6 (`OUTPUT`). All the time-trace plots show Level 6 output evolving over time. For 2-D simulations, we plot only Level 1 (stimulus) and Level 6 (output) outputs. Here again, the time-trace plots show the Level 6 outputs evolving at successive time-intervals.

Item 1: Filling-in

Figure 1 shows simulations of COCE and its non-illusory counterpart. The outputs of both simulations predict a step shaped brightness profile.

Figure 2 shows how solutions evolve over time. The X-axis plots cell-indices and the Y-axis plots time. To be more precise, Y-axis plots the number of steps taken for the ode-solver to arrive at the solution. In this representation, brightness is coded by colors. Dark blue corresponds to "dark" and dark red corresponds to "bright" as shown by the colorbars.

It is important to note that graphs which use color are specific to corresponding examples under consideration. Comparisons of brightness across simulations cannot be made because the same colors might code for different brightness values in different simulations. This is because the range of brightness values in a given simulation is mapped to the entire color spectrum.

Item 2: Smoothly Modulating Inputs

In this section, we examine the behavior of the model for smoothly modulating inputs. Figure 3 shows the profiles for two sinusoidal inputs which differ in mean luminance level. Figure 4 shows the time trace for this simulation. In the left panel, we see that the brightness percept is more like a square-wave than a sinusoidal wave. In the right panel, the high mean luminance reduces the contrast differences in the brightness percept.

Figure 5 shows the model behavior for two sinusoidal input luminance distributions. The two distributions differ in amplitude, but still the brightness percept arising from

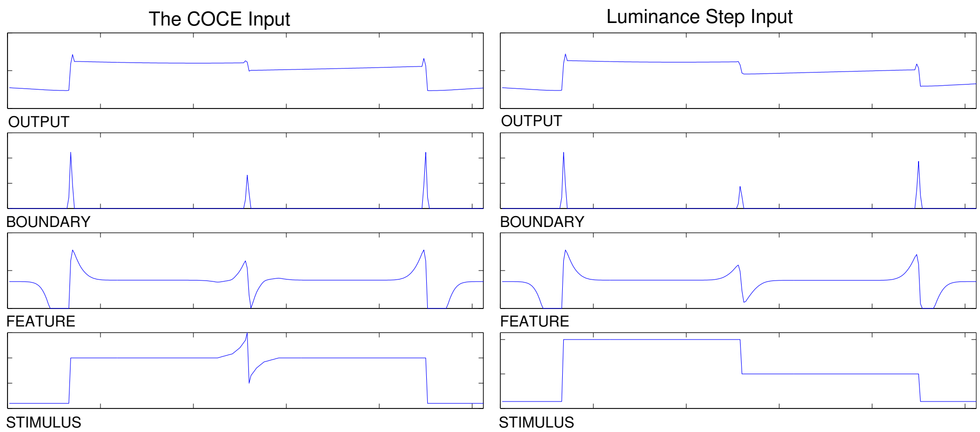

Figure 1: Item 1 – Simulation of COCE and its nonillusory counterpart. The outputs of both predict a step-shaped brightness profile.

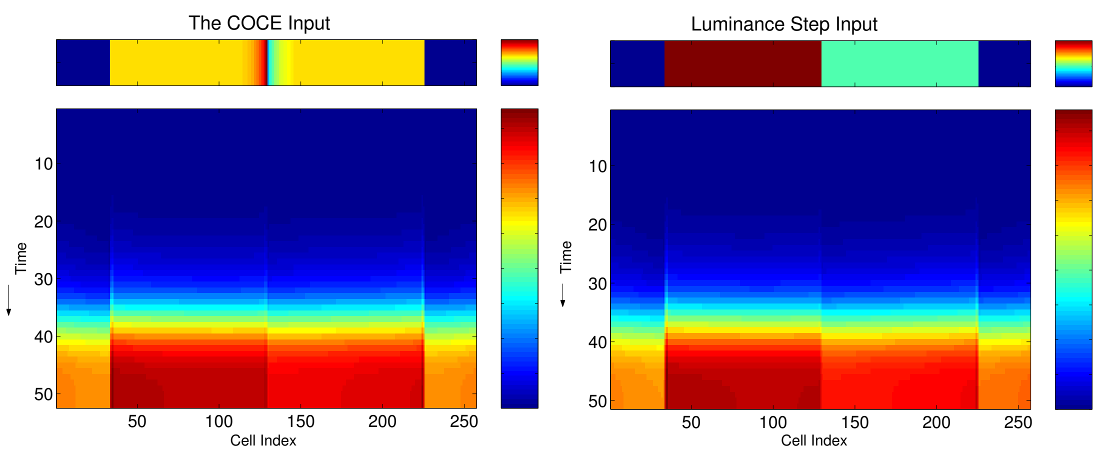

Figure 2: Item 1 – Time trace of the simulations shown in Figure 1. Different brightness levels are shown by different colors, with the vertical color-bars on the right providing the scale. Blue corresponds to "dark" and red corresponds to "bright". Horizontal bars at the top show input luminance distributions.

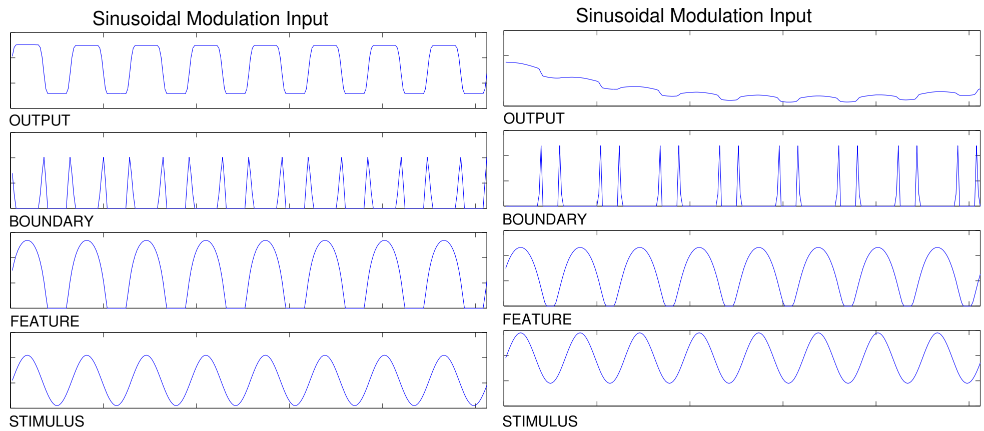

Figure 3: Item 2 – Sinusoidal Input. The two simulations differ in the mean luminance level (11 in the left panel and 19 in the right panel, amplitude is 10 in both cases).

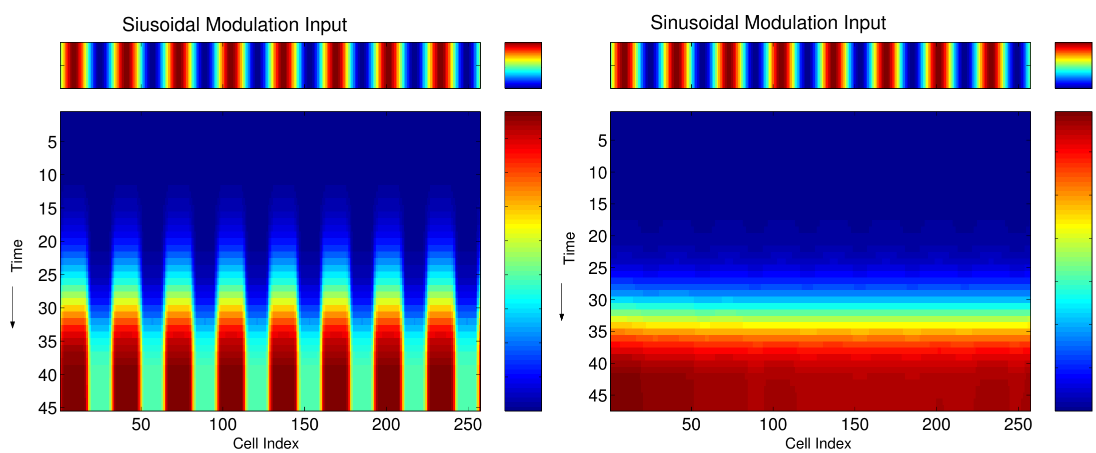

Figure 4: Item 2 – Time trace of the simulations shown in Figure 3. Different brightness levels are shown by different colors, with the vertical color-bars on the right providing the scale. Blue corresponds to "dark" and red corresponds to "bright". Horizontal bars at the top show input luminance distributions.

these are very similar. Figure 6 shows the time-trace of these simulations. As mentioned earlier, the important thing to notice here is that the percept profile is more like a square wave rather than a smooth sine wave.

It is not possible to make the outputs look more "veridical" i.e. more like a sine wave. This is easy to explain if one considers the boundaries formed (labelled `BOUNDARY` in figures 3 and 5). Level 6 of the model spreads all the activity by diffusion within boundaries. Hence, we see (almost) constant brightness within a region surrounded by BCS boundaries instead of a smooth modulation as in the input.

Item 3: Brightness Ramps

I was unable to find a suitable combination of inputs and parameters that yields a noticeable brightness gradient at equilibrium in the shape of a ramp. This is tricky because the model (especially level 6) is set up in such a way that shallow gradients within one region is homogenized. In other words, consider a region formed by the boundaries of the BCS. Even if there exists a shallow gradient in brightness in the input luminance distribution in the corresponding region, the diffusion activity of level 6 distributes the activity all over the region. This implies that shallow gradients are eliminated at the percept stage.

Item 4: Mach Bands

Figure 7 shows the outputs when the input luminance distribution is in the form of a ramp. The left panel shows 1-D profiles while the right panel shows the time trace of the simulation. We notice that there is no "mach band" percept in the output. This is because of the diffusion activity of Level 6 of the model which has a tendency to spread the activity of all neurons within a region. Hence, there is no possibility of appearance of narrow mach bands.

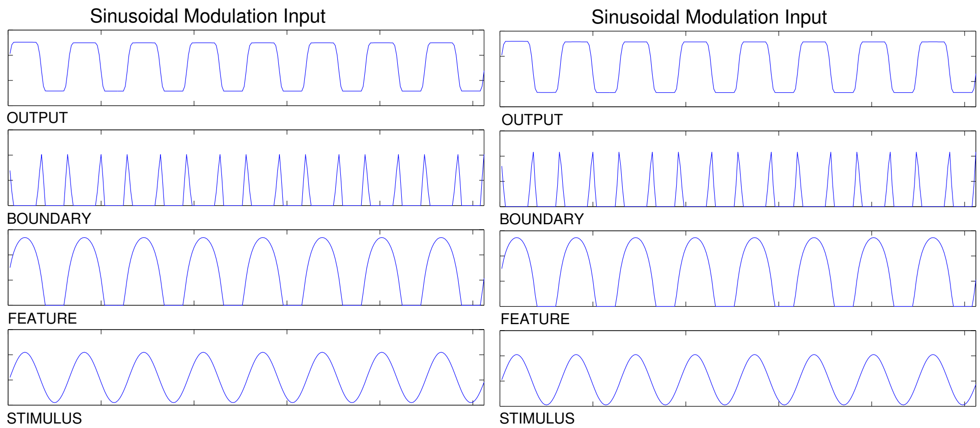

Figure 5: Item 2 – Sinusoidal Input. The two simulations differ in the amplitude of the luminance. The amplitude of the input on the right panel is double (20) the amplitude in the left panel (10) and the mean luminances are 21 and 11 respectively. As we can see from the percept profiles, the difference is barely perceptible.

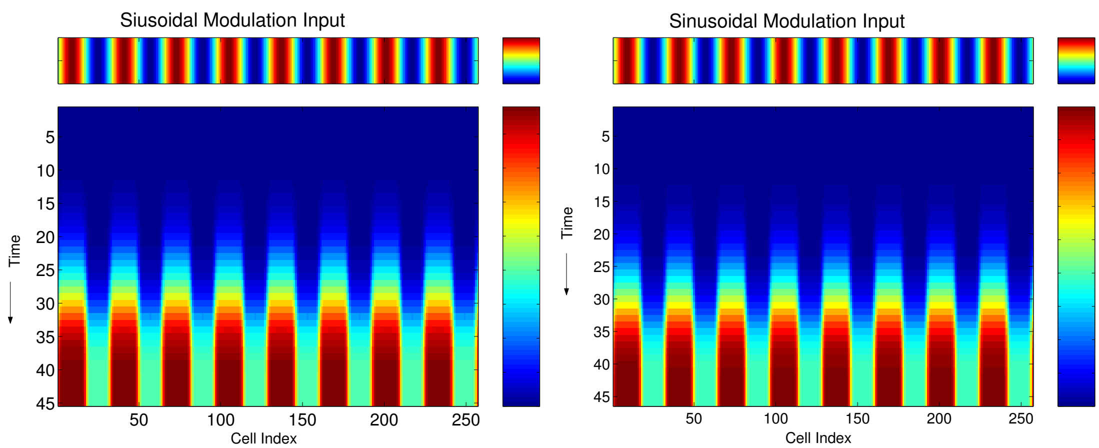

Figure 6: Item 2 – Time trace of the simulations shown in Figure 5. Different brightness levels are shown by different colors, with the vertical color-bars on the right providing the scale. Blue corresponds to “dark” and red corresponds to “bright”. Horizontal bars at the top show input luminance distributions.

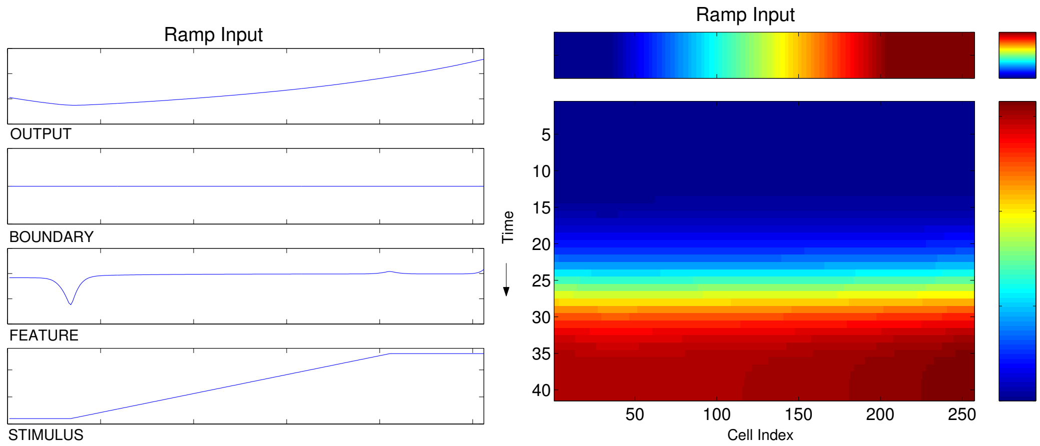

Figure 7: Item 4 – Brightness Ramp input. The left panel shows 1-D profiles while the right panel shows the time trace of the simulation. In the right panel, different brightness levels are shown by different colors, with the vertical color-bars on the right providing the scale. Blue corresponds to "dark" and red corresponds to "bright". The horizontal bar at the top shows the input luminance distribution.

Item 5: Series of cusps and ramps

In Item 1, we showed that percept arising out of a luminance cusp will be a luminance step. The model predicted this correctly and this misled some people to believe that the model would predict a "staircase" percept (a series of luminance steps) when presented with a series of luminance cusps.

Figure 8 shows the model behavior for a series of cusps and a series of ramps. Consider the series of cusps. Instead of a "staircase" percept, the model correctly predicts that brightness percept will differ only for cusps at the two ends. All the interior cusps give rise to similar percepts. Figure 9 shows the evolution of these outputs over time.

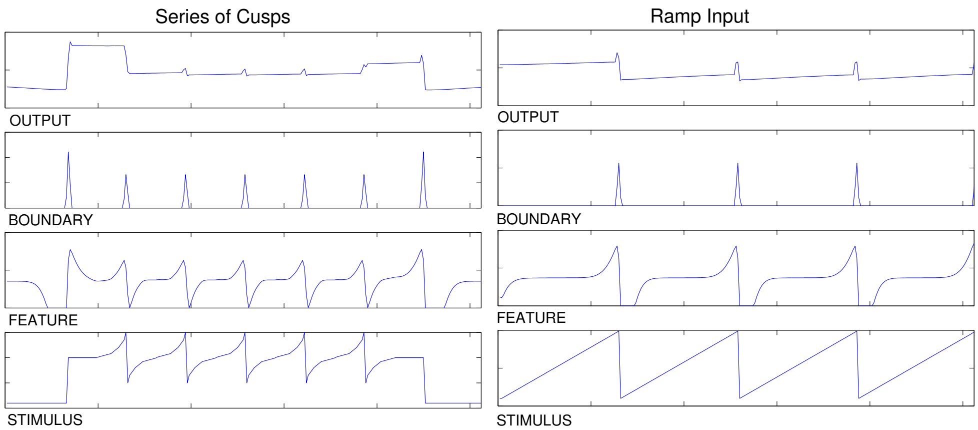

Figure 8: Item 5 – Series of cusps (left panel) and multiple ramps (right panel). In case of cusps, we notice that brightness percept differs only for the cusps at the end. Interior cusps give rise to a similar percept.

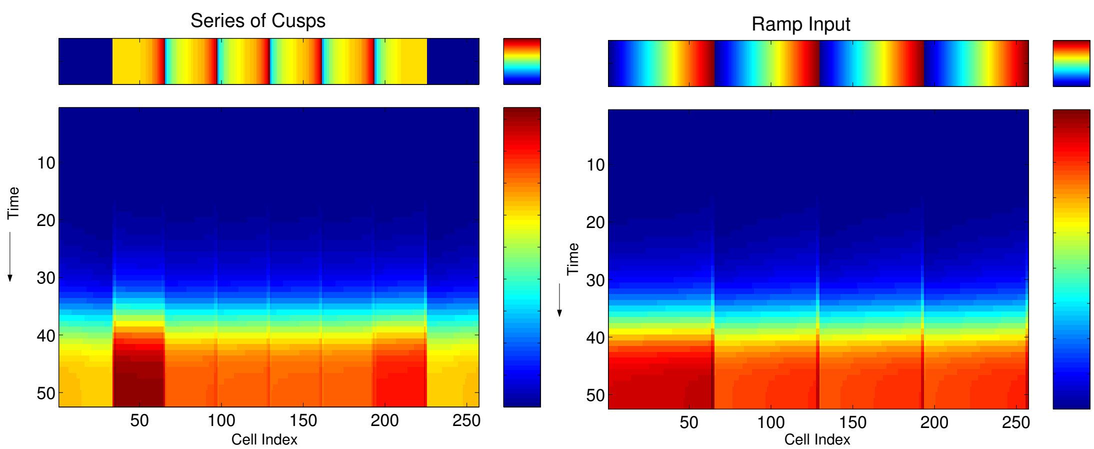

Figure 9: Item 5 – Time trace of simulations shown in figure 8. In the left panel, the input has a series of cusps while in the right panel, there are multiple ramps. Different brightness levels are shown by different colors, with the vertical color-bars on the right providing the scale. Blue corresponds to "dark" and red corresponds to "bright". Horizontal bars at the top show input luminance distributions.

Item 6: 2D Simulations

In this section, we examine 2-D simulations. In all the figures that follow, we represent increasing brightness levels using colors starting from blue at the lower extreme to red at the higher extreme.

Figure 10 shows the input and percept distributions of a typical Craik-O'Brein-Cornsweet effect. In figure 12, the input distribution is similar but there is no distinct background. This model correctly predicts that the illusory effect is more pronounced in the former case than the latter case. Figures 11 and 13 show the output of level 6 of the model at successive time instants. One can actually "see" the filling-in process in action.

Figures 14 and 16 illustrate the Koffka-Benussi ring effect. The background is composed of two vertical homogeneous regions of different luminances, the luminance of the left region being greater than that of the region on the right. The foreground is a square-annulus shaped homogeneous region of intermediate luminance. If the annulus is continuous as shown in figure 16, we see that the square annulus is perceived to be homogeneous. However, if the annulus has a vertical break in the middle as shown in figure 14, then we perceive the right half of the annulus to be brighter. Figures 17 and 15 show the output of level 6 of the model at successive time instants for the continuous annulus case and the broken annulus case respectively.

Conclusions

The model we have discussed deals only with monocular achromatic brightness effects. We have successfully simulated observed illusions like the COCE (in both 1-D and 2-D) and the Koffka-Benussi Ring effect. The model correctly predicts the observed brightness percepts in these cases. However, there are many free parameters which play an important role in the formation of the output. The parameter space is huge and a more thorough study is required to understand and analyze the exact dependence of the model on the parameter choices.

References

[1] Stephen Grossberg and Dejan Todorović. Neural dynamics of 1-d and 2-d brightness perception: A unified model of classical and recent phenomena. *Perception and Psychophysics*, 43:241–277, 1988.

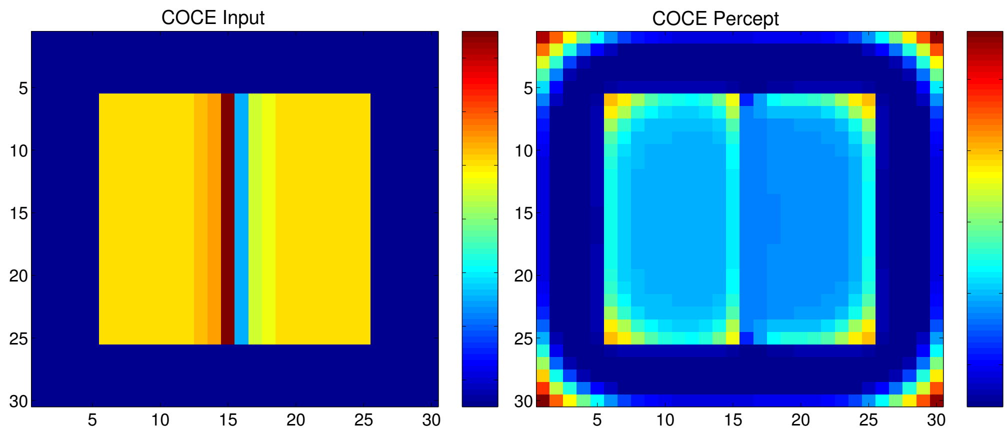

Figure 10: COCE input and percept.

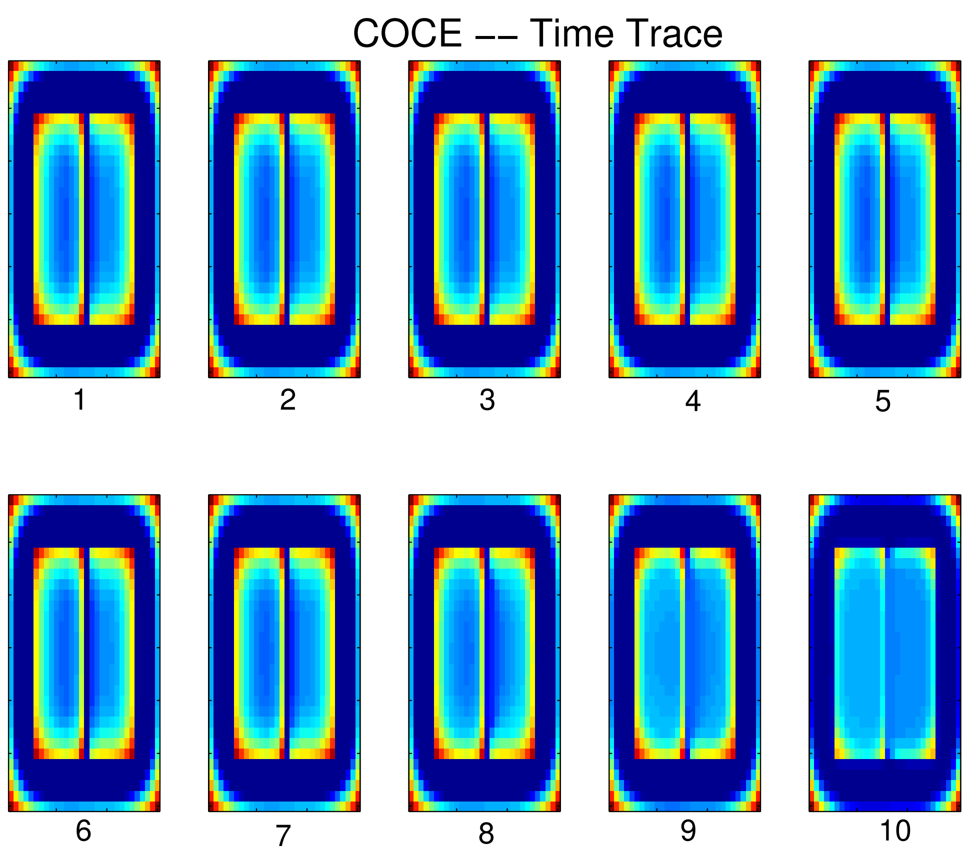

Figure 11: COCE – Time trace.

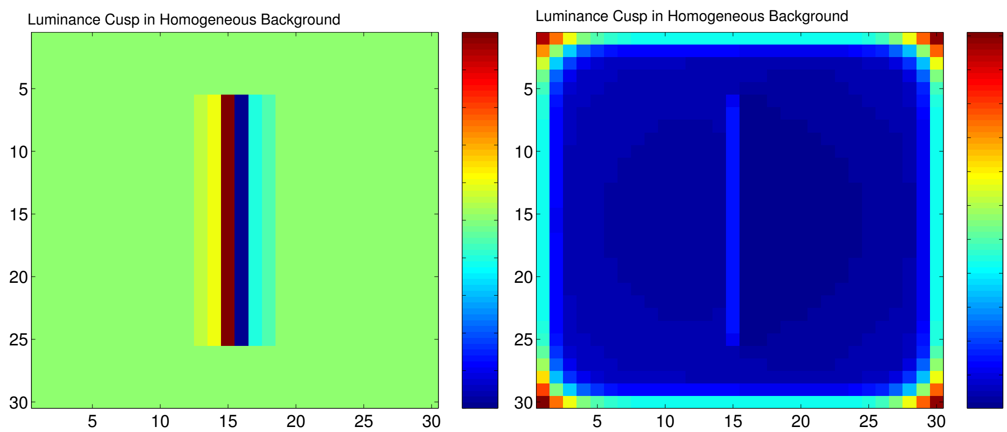

Figure 12: Luminance cusp in a homogeneous background – Input and percept.

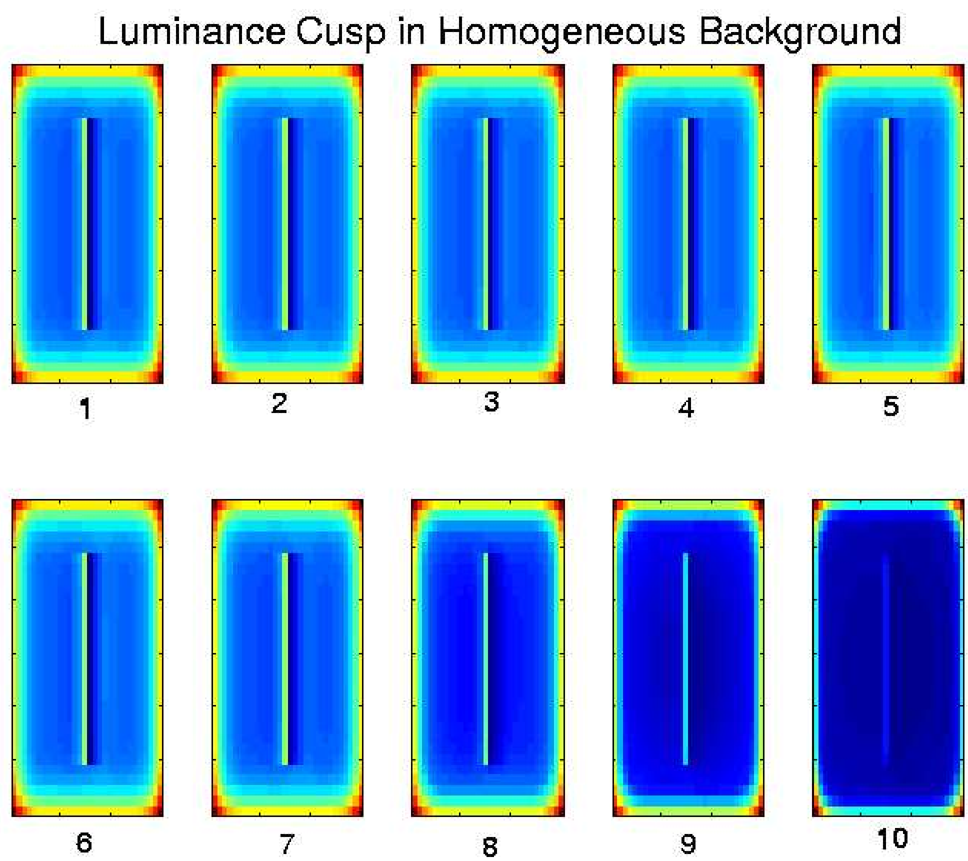

Figure 13: Time trace for the simulation shown in Figure 12.

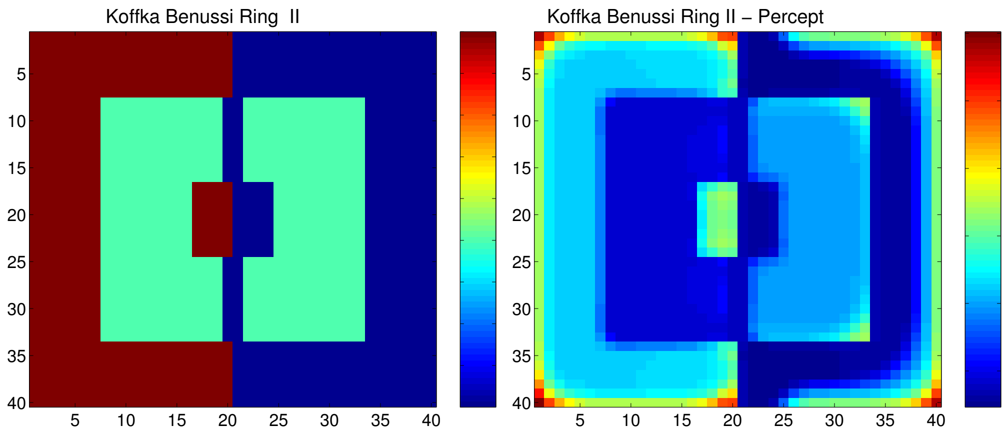

Figure 14: Koffka-Benussi Ring – Divided annulus. Input and percept.

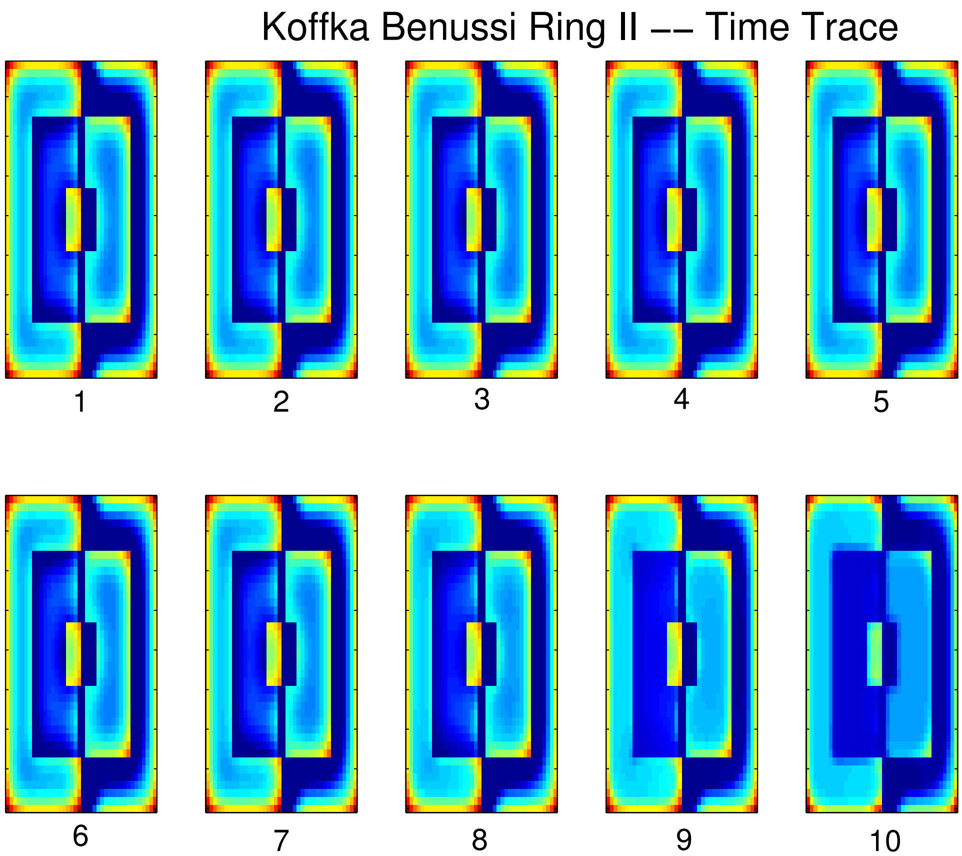

Figure 15: Time trace for the simulation shown in Figure 14.

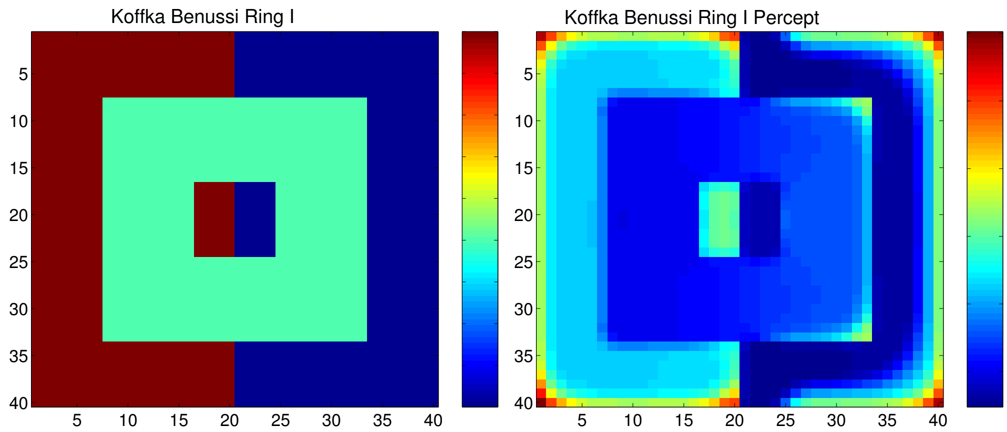

Figure 16: Koffka-Benussi Ring – Continuous annulus. Input and percept.

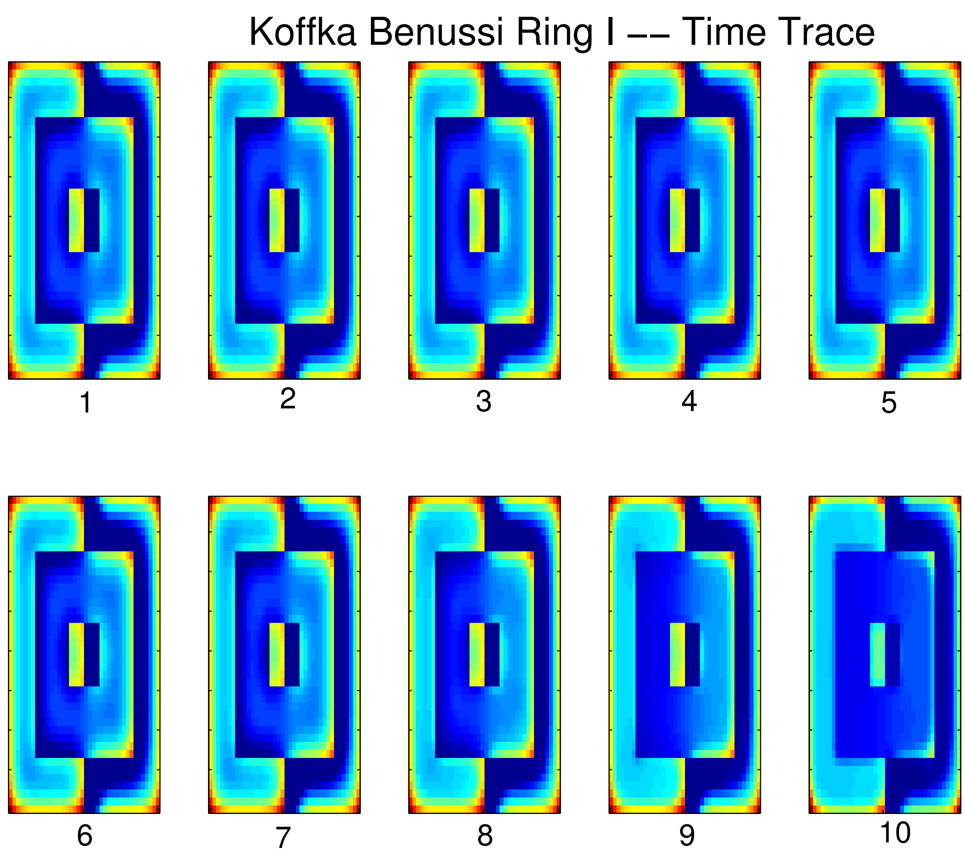

Figure 17: Time trace for the simulation shown in Figure 16.