

`insect_decision`

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1 Introduction

`insect_decision` is a collection of numerical approximations of dynamical models of binary nest selection in social insects, as reported in Marshall et al. (2009). I also include my own model of the impact of gaze following on binary decision making, which is inspired by these models.

The program includes a simple GUI allowing the user to modify parameters and visualize how doing so changes the behavior of the model; this is written using the open source Qt framework. The approximations are based on the 4th order Runge-Kutta method.

2 The Usher-McClelland Model

The basic idea behind the Usher-McClelland model (figure 1) of binary decision making is to model the two options as neural activities. The activity for each option is increased by the input signal for that option, the activity is decreased by (i) inhibitory connections from the competing option, and (ii) leakage. The system is therefore modeled by:

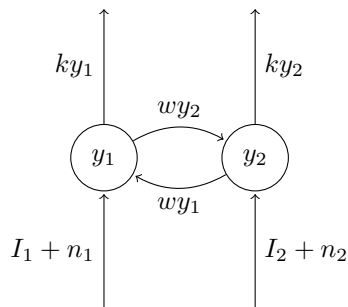


Figure 1: The Usher-McClelland model.

$$\begin{aligned}\dot{y}_1 &= (I_1 + n_1) - y_1k - y_2w \\ \dot{y}_2 &= (I_2 + n_2) - y_2k - y_1w\end{aligned}\tag{1}$$

Where I_i is the input to option i , n_i is noise with mean 0.0 and a small standard deviation, k is the decay rate, and w is the weight between options.

3 The simplified Pratt Model

The simplified Pratt model is based on the following scenario: a colony of insects is looking to change from a source nest s to one of two alternatives y_1 and y_2 . Insects discover each nest at a rate q_i ; this is analogous to the input signals to the two neural activities in the Usher-McClelland model. Scouts from s will be attracted to y_1 and y_2 at these rates. Furthermore, insects already committed to a new nest can recruit (i.e., by tandem running) those from s at recruitment rates r'_1 and r'_2 , up to the point where s is empty, at which point the number of recruited insects is zero. Insects also spontaneously wander off from each nest after they've been committed, returning to s ; this is analogous to the leakage of the Usher-McClelland model. Finally, insects may also wander away from a nest only to end up in the competing nest – this is called ‘direct transfer’ between y_1 and y_2 , and the transfer rates are r_1 and r_2 . Letting n be noise terms with mean 0.0 and a small standard deviation, this yields the following model:

$$\begin{aligned}\dot{y}_1 &= (s - y_1 - y_2)(q_1 + n_{q_1}) \\ &\quad + y_1r'_1(s) \\ &\quad + y_2(r_2 + n_{r_2}) \\ &\quad - y_1(r_1 + n_{r_1}) \\ &\quad - y_1(k_1 + n_{k_1}) \\ \dot{y}_2 &= (s - y_1 - y_2)(q_2 + n_{q_2}) \\ &\quad + y_2r'_1(s) \\ &\quad + y_1(r_1 + n_{r_1}) \\ &\quad - y_2(r_2 + n_{r_2}) \\ &\quad - y_2(k_2 + n_{k_2})\end{aligned}\tag{2}$$

Where $(s - y_1 - y_2)$ is the current population remaining in s , and $r'_i(s) = r'_i + n_{r'_i}$ if $s > 0$, and 0 otherwise.

Note that in the Usher-McClelland model, the activity of one ensemble inhibits the activity of the other. In the simplified Pratt model, however, the number of insects directly transferring from one nest to another is not a function of the number of insects in the nest receiving the new arrivals. That is, for example, the activity of y_i has no influence on how many insects from y_2 directly transfer to y_1 (and hence y_1 has no ‘inhibitory’ influence on the activity of y_2).

4 The simplified indirect Britton model

The simplified indirect Britton model is like the simplified Pratt model, except (i) there is no direct transfer between y_1 and y_2 , and (ii) the number of ants recruited from s is modified by a factor of the current population of s (i.e., rather than recruit 0 or $y_1(r'_1 + n_{r'_1})$ ants at each time step, the new model recruits $y_1(s - y_1 - y_2)(r'_1 + n_{r'_1})$ ants). Since we are assuming the initial population is $s \geq 1$, this means more ants are typically recruited than in the Pratt model.

$$\begin{aligned}
 \dot{y}_1 &= (s - y_1 - y_2)(q_1 + n_{q_1}) \\
 &\quad + y_1(s - y_1 - y_2)(r'_1 + n_{r'_1}) \\
 &\quad - y_1(k_1 + n_{k_1}) \\
 \dot{y}_2 &= (s - y_1 - y_2)(q_2 + n_{q_2}) \\
 &\quad + y_2(s - y_1 - y_2)(r'_2 + n_{r'_2}) \\
 &\quad - y_1(k_2 + n_{k_2})
 \end{aligned} \tag{3}$$

5 The simplified direct Britton model

The simplified direct Britton model is nearly identical to the simplified indirect model. First, the rate at which recruits ‘leak’ back to s is no longer distinct for the two nests, and the noise term has been eliminated. Second and more importantly, there is now direct transfer between nests proportional to both the number of insects available to be recruited and the number available to do the recruiting. This term thus puts the model back on par with the Usher-McClelland model insofar as the activity of one option can suppress the activity of the other.

$$\begin{aligned}
 \dot{y}_1 &= (s - y_1 - y_2)(q_1 + n_{q_1}) \\
 &\quad + y_1(s - y_1 - y_2)(r'_1 + n_{r'_1}) \\
 &\quad - y_1 k \\
 &\quad + y_1 y_2 (r_1 - r_2 + n_{r_1} - n_{r_2}) \\
 \dot{y}_2 &= (s - y_1 - y_2)(q_2 + n_{q_2}) \\
 &\quad + y_2(s - y_1 - y_2)(r'_2 + n_{r'_2}) \\
 &\quad - y_1 k \\
 &\quad - y_1 y_2 (r_1 - r_2 + n_{r_1} - n_{r_2})
 \end{aligned} \tag{4}$$

6 The gaze following model

It is well established that humans use the direction-of-gaze of conspecifics as a source of information for deciding where to search (e.g., for food), or more generally, for establishing joint attention. A classic experimental paradigm (Brooks

and Meltzoff, 2002) has an experimenter look either to the left or right for some amount of time, with eyes open or shut; infants of a certain age will look towards the same location in the eyes-open case, but not in the eyes-shut case.

The model presented here is a generalization of this paradigm, inspired by the structure of the models surveyed above. The basic idea is to extend the Usher-McClelland model by giving each option a gaze signal in addition to any initial condition (i.e., priming) or ongoing, non-gaze-related input (e.g., flashing lights or other distractors). Specifically, there are two targets, t_1 and t_2 , arranged somewhere in the field of view, from 0 to 180 degrees, and the goal of the modeled subject is to choose between these options. As in the Usher-McClelland model, this choice is represented as corresponding neural activities y_1 and y_2 , corresponding to t_1 and t_2 , respectively. A hypothetical conspecific then gazes at some location t_g in this field of view (t_g need not be identical to t_1 or t_2). Each y_i receives a signal inversely proportional to the distance between t_g and t_i . Note the gaze itself is noisy – t_g is the mean of a normal distribution with an adjustable standard deviation. The value of the gaze signal ranges from a maximum of g to 0.0, and the gaze is maintained for some duration $0.0 \leq d_g \leq d$, where d is the duration of the entire simulation.

At the time of writing, the function for calculating gaze signals at each time step is linear:

$$f(t_i) = \left(-\frac{1}{a}(|t_g - t_i| + z)\right) + 1 \quad (5)$$

and

$$g_i = \begin{cases} f(t_i)g, & \text{if } f(t_i) > 0.0 \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

where a is the y -intercept, z is the sample point from the normal distribution around t_g , and g is the maximum gaze signal value. Note z is subtracted when $t_i > t_g$, and that the gaze input is always 0.0 if the gaze is not active.

This yields the following model defined by equation 7 and depicted in figure 2 (note noise terms are omitted from the figure).

$$\begin{aligned} \dot{y}_1 &= (I_1 + n_{I_1}) \\ &\quad + (g_1 + n_{g_1}) \\ &\quad - (y_1 k_1 + n_{k_1}) \\ &\quad - (y_2 w_2 + n_{w_2}) \\ \dot{y}_2 &= (I_2 + n_{I_2}) \\ &\quad + (g_2 + n_{g_2}) \\ &\quad - (y_2 k_2 + n_{k_2}) \\ &\quad - (y_1 w_1 + n_{w_1}) \end{aligned} \quad (7)$$

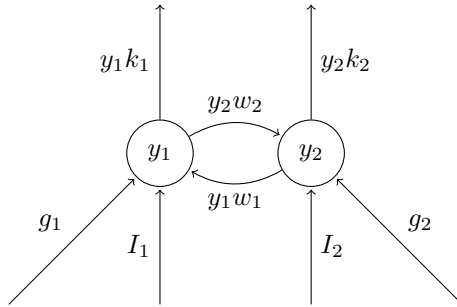


Figure 2: The gaze following model.

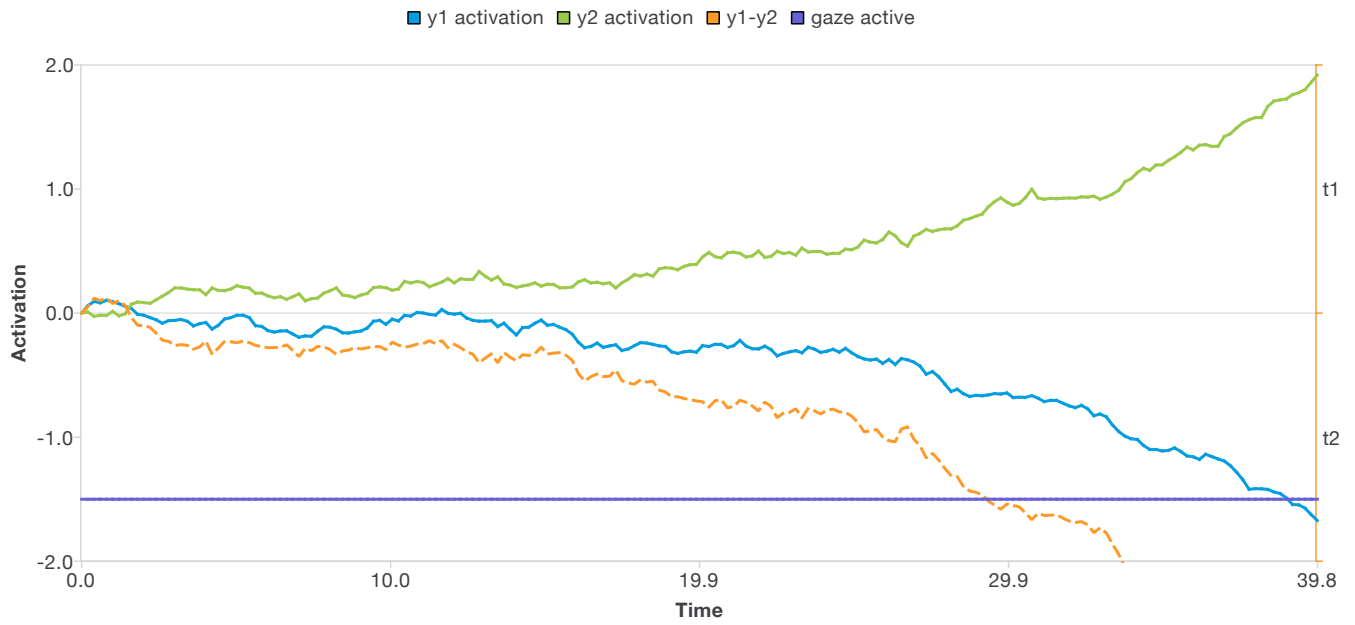


Figure 3: Example run with no priming and no gaze.

Of course, for purposes of this project I make no attempt to validate this model, but it does exhibit qualitatively interesting behavior. For instance, figure 3 shows a typical run of the model with no priming (i.e., initial values of $y_i = 0.0$), and no gaze. The blue line indicates the activation of y_1 , the green line the activation of y_2 , and the flat purple line is a (more-or-less) square wave showing when gaze is active (in this case, never). The orange line is the difference $y_1 - y_2$; so, if the difference trends up, target t_1 is favored, and if the difference trends down, t_2 is favored – these outcomes are indicated on the right-hand vertical axis. So, in the case depicted in figure 3, noise and inhibitory feedback eventually drive the model to choose option t_2 .

Figure 4 illustrates what happens when a gaze directed at target t_1 is introduced ($d_g = 2.0$, $g = 0.2$): the additional input pushes the system to choose that target. However, the influence of the gaze can be overridden by priming: figure 5 shows that a gaze of this duration at this intensity is insufficient to cause the system to choose t_1 under a modest level of priming for t_2 ($y_2 = 0.2$ at time zero).

Increasing the duration of the gaze (from 2.0 to 3.0) is sufficient to flip the system back to choosing t_1 , as shown in figure 6. Increasing the amount of attention the subject devotes to the gaze (i.e., the value of g) is also sufficient to overcome this priming (not pictured).

Finally, if the gaze is moved away from t_1 by a small amount (in this case, a single degree), the system registers the influence of the gaze, but once again chooses t_2 , as shown in figure 7. However, increasing the standard deviation of the gaze (so that it spreads out across a wider range than before, i.e., it's noisier) can compensate (figure 8).

As noted above, we can think of the input signals I_i as ongoing distractors drawing the attention of a subject to a target, g as a measure of the attention a subject devotes to gaze information, the values of each y_i at time zero as the result of priming, k_i as decay, and w_i as inhibition between the competing alternatives. Taken together with the fact a gaze may be off-target and have more or less variation in accurately identifying a target, the examples just surveyed are suggestive insofar as they appear to capture some of the potentially complex spatial and temporal interactions between these factors.

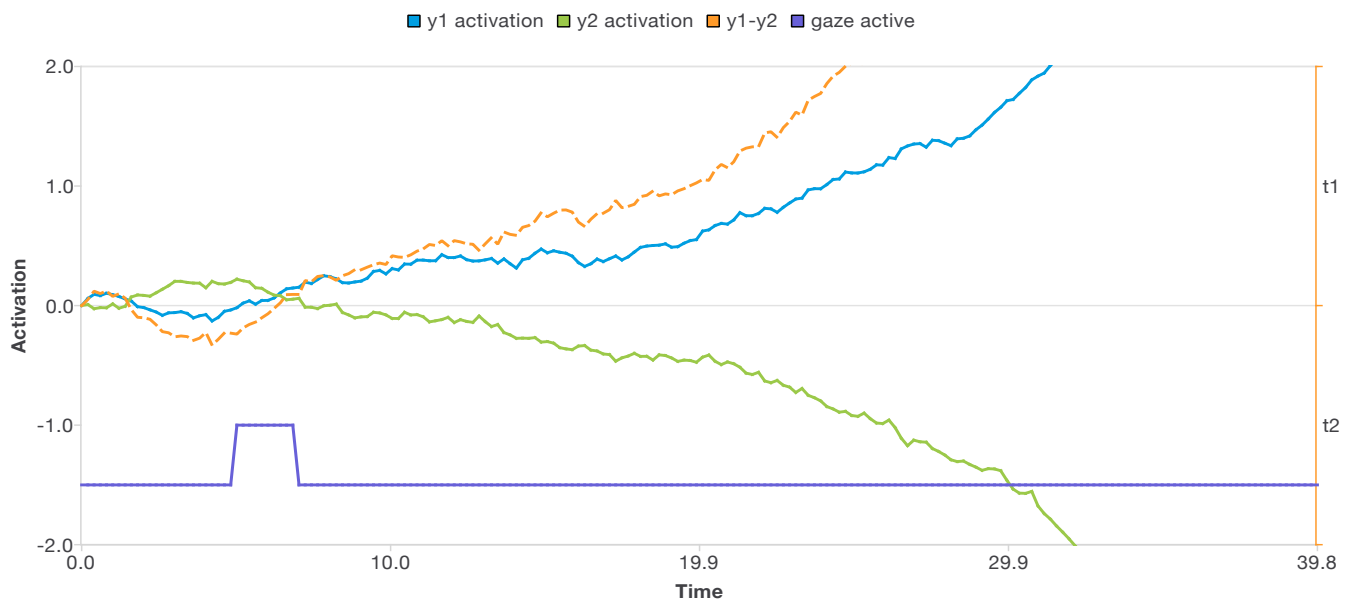


Figure 4: Example run with no priming and a gaze on target t_1 lasting 2 time units.

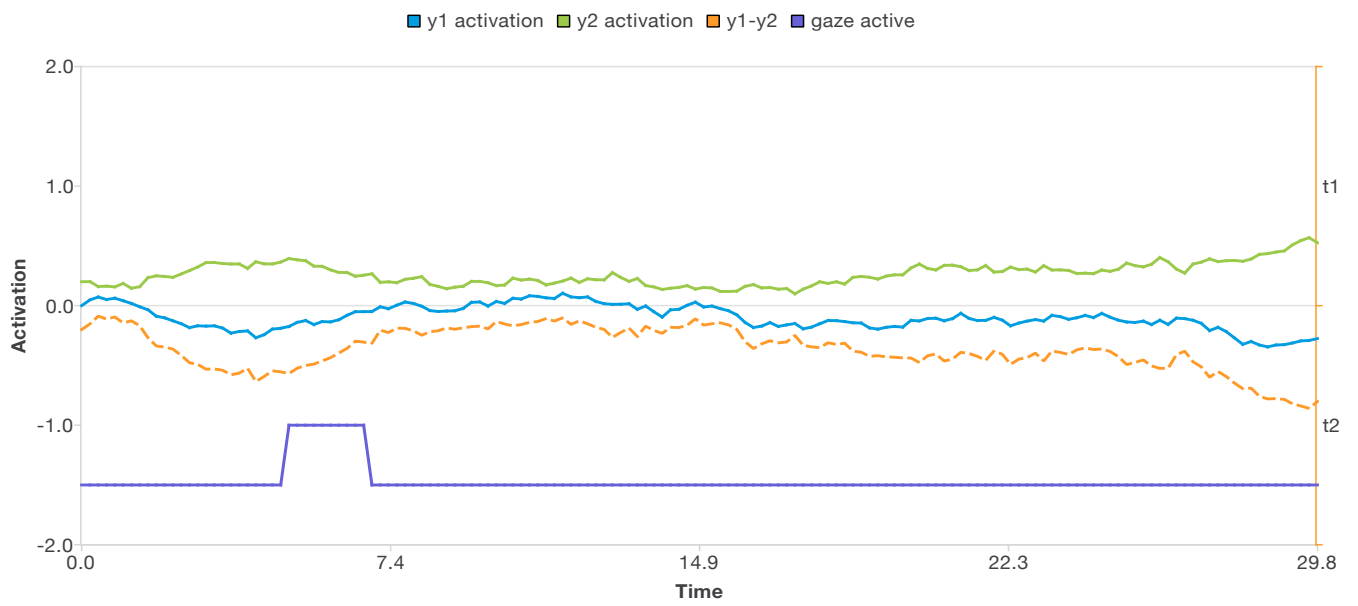


Figure 5: Example run with small priming to t_2 and a gaze on t_1 lasting 2 time units; in contrast to figure 4, the gaze signal is no longer sufficient to cause the system to choose t_1 .

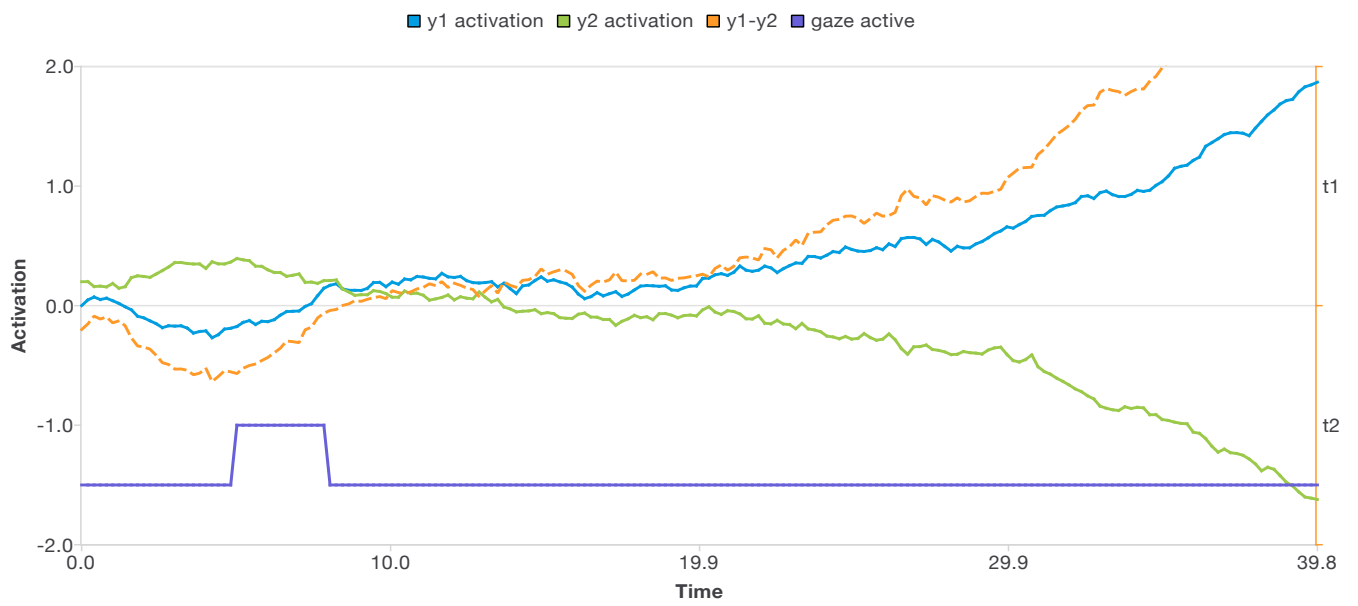


Figure 6: By extending the duration of the gaze directed at target t_1 , the priming introduced in figure 5 is overcome, and the system once again chooses t_1 .

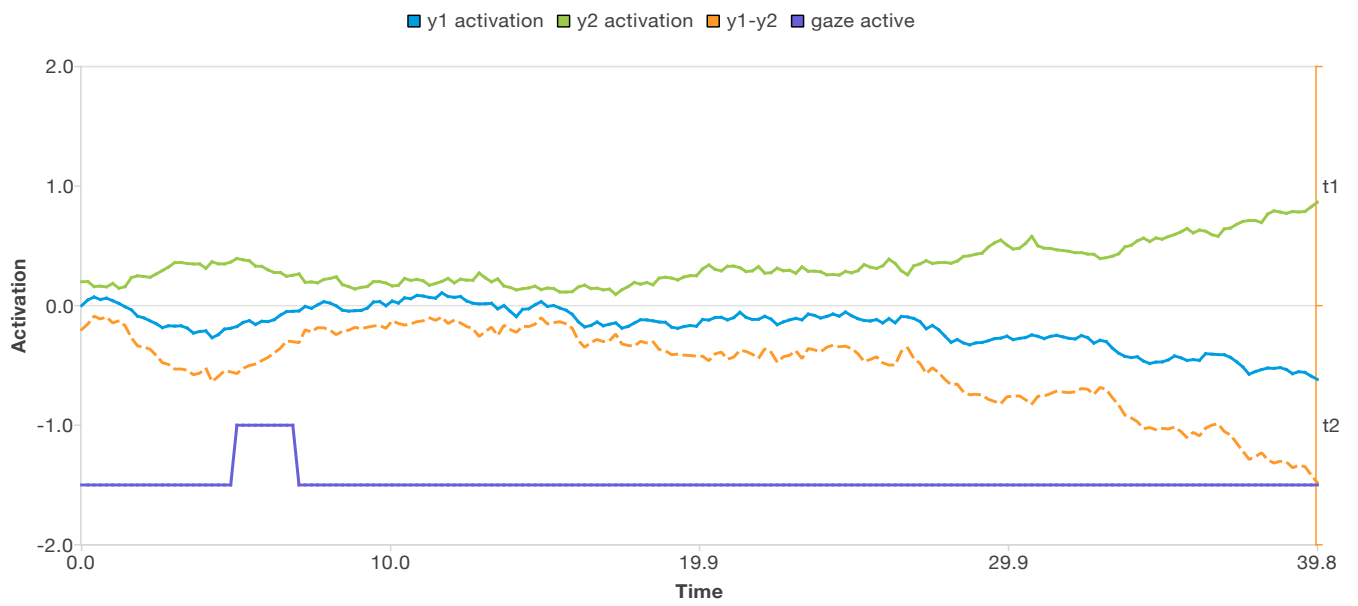


Figure 7: When the gaze is shifted away by a degree from the location occupied by t_1 , the system still registers the influence of the gaze, but nonetheless reverts to choosing t_2 .

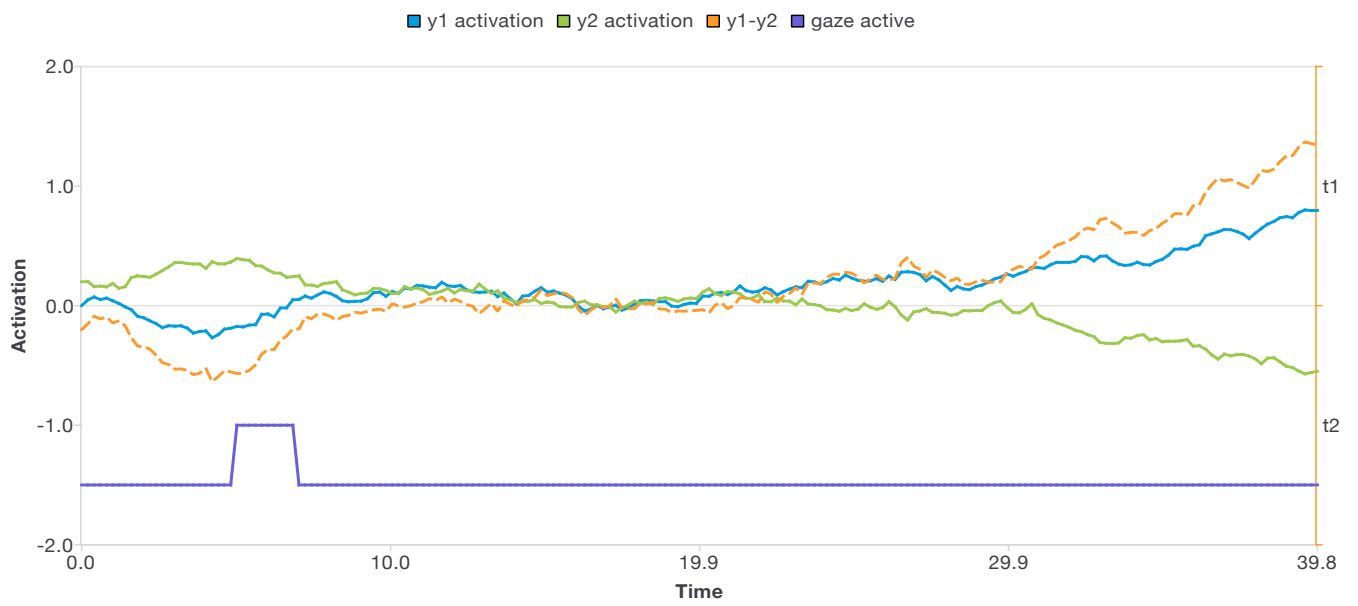


Figure 8: By increasing the spread of the gaze (from a standard deviation of 0.1 to 5.0), the fact the gaze directed at t_1 is off by a degree can be overcome, and the system again chooses t_1 .

References

- Brooks, Rechele and Andrew N. Meltzoff (2002). “The importance of eyes: How infants interpret adult looking behavior”. In: *Developmental Psychology* 38.6, pp. 958–966. ISSN: 1939-0599 0012-1649. DOI: 10.1037/0012-1649.38.6.958.
- Marshall, James A. R. et al. (2009). “On optimal decision-making in brains and social insect colonies”. In: *Journal of The Royal Society Interface*, rsif.2008.0511. ISSN: 1742-5689, 1742-5662. DOI: 10.1098/rsif.2008.0511.