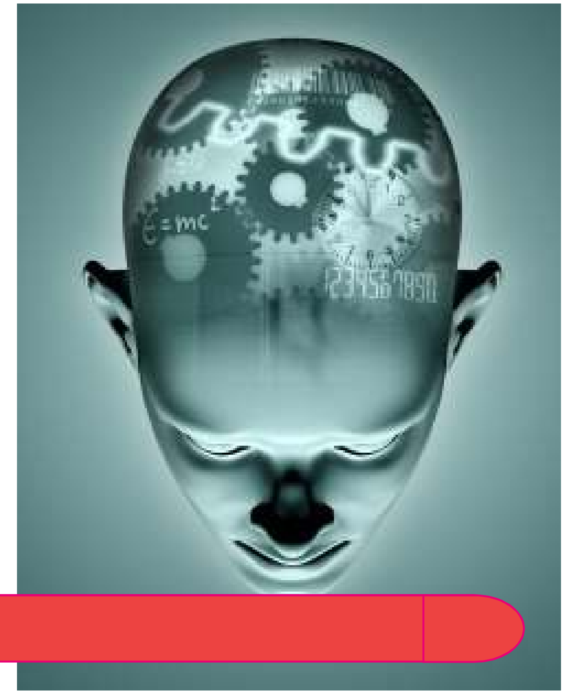
Neuroeconomics :

Neuroscience of decision making

Lecture N3



Introducing brain models of decision making and choice

Vasily Klucharev

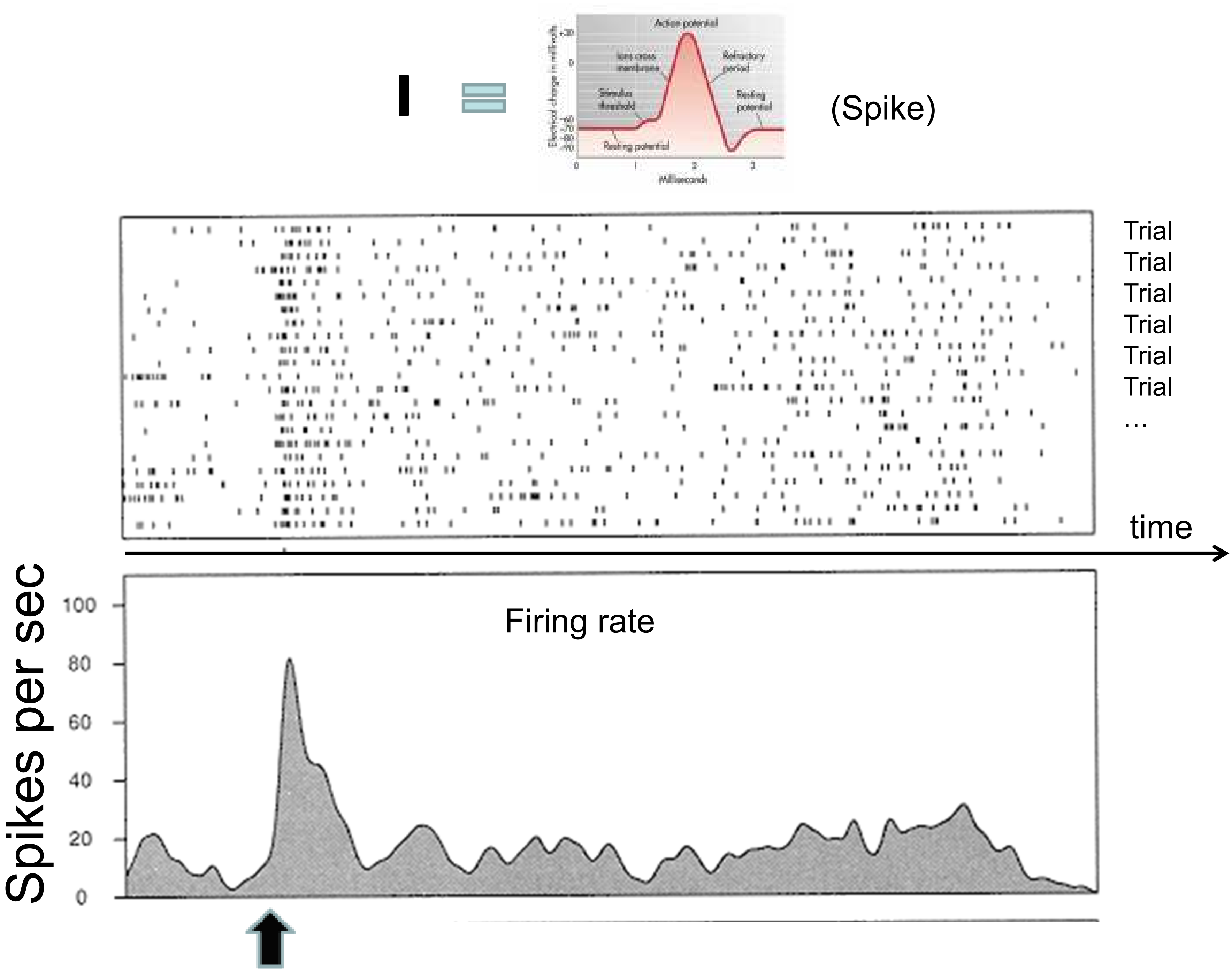
- Higher School of Economics

Neuroeconomics

- The goal of neuroeconomics discipline is to understand the processes that connect sensation and action by revealing the neurobiological mechanisms by which decisions are made.

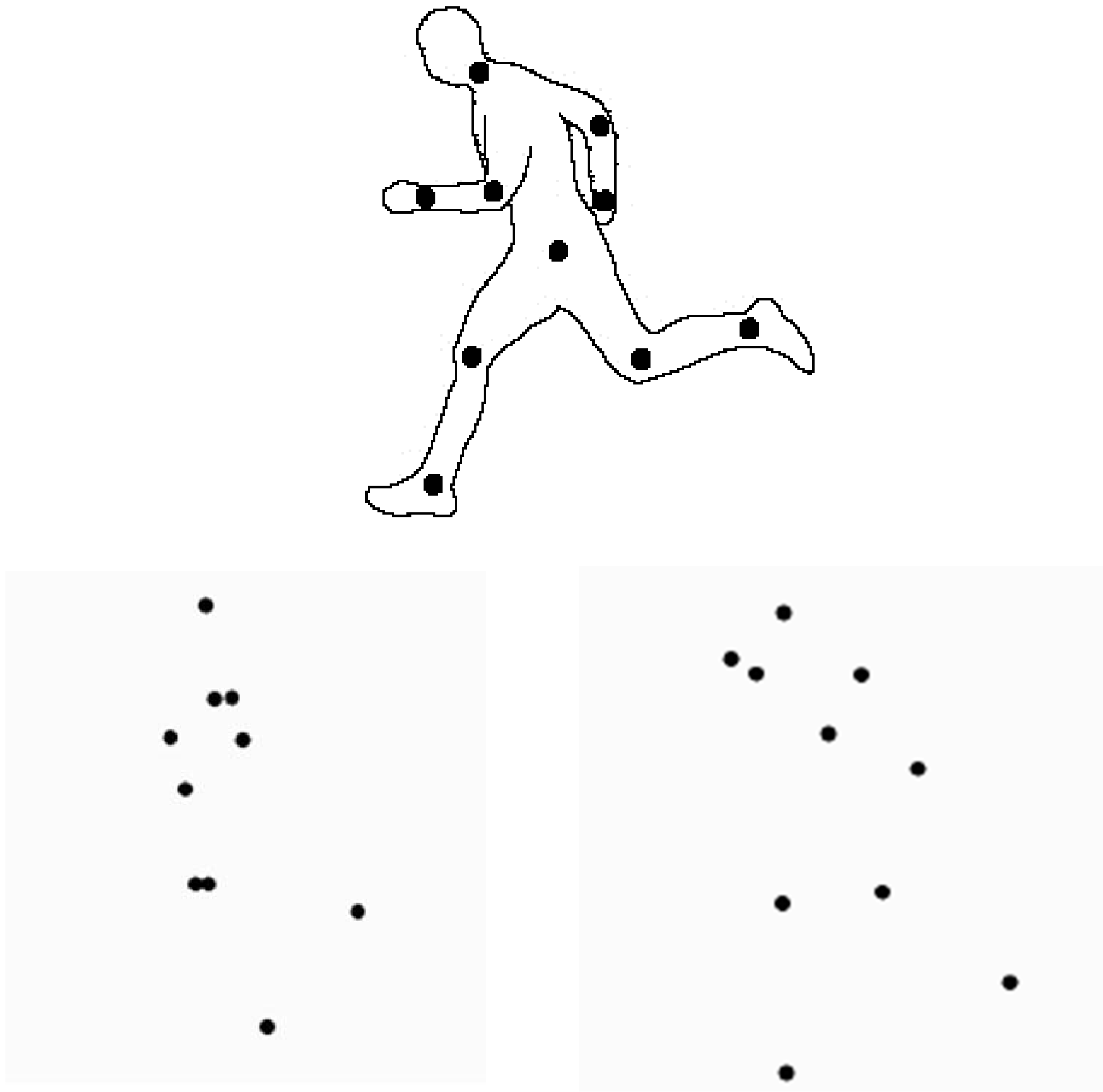
Decision-making

Adopted from Glimcher&Rustichini, Science 2004



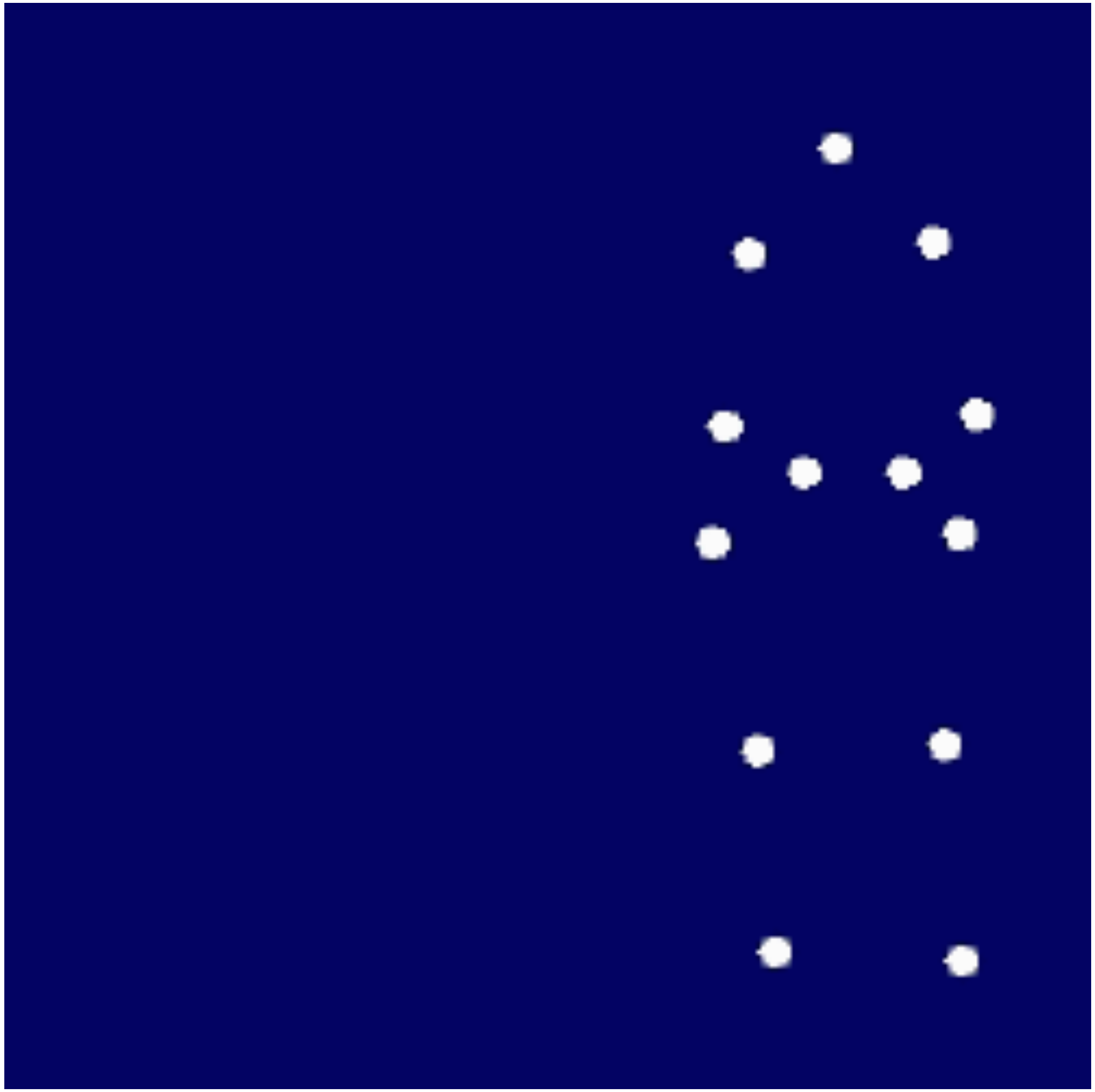
(Spike)
Trial
Trial
Trial
Trial
Trial
Trial
…
time
Firing rate
Spikes per sec
100
80
60
40
20
0

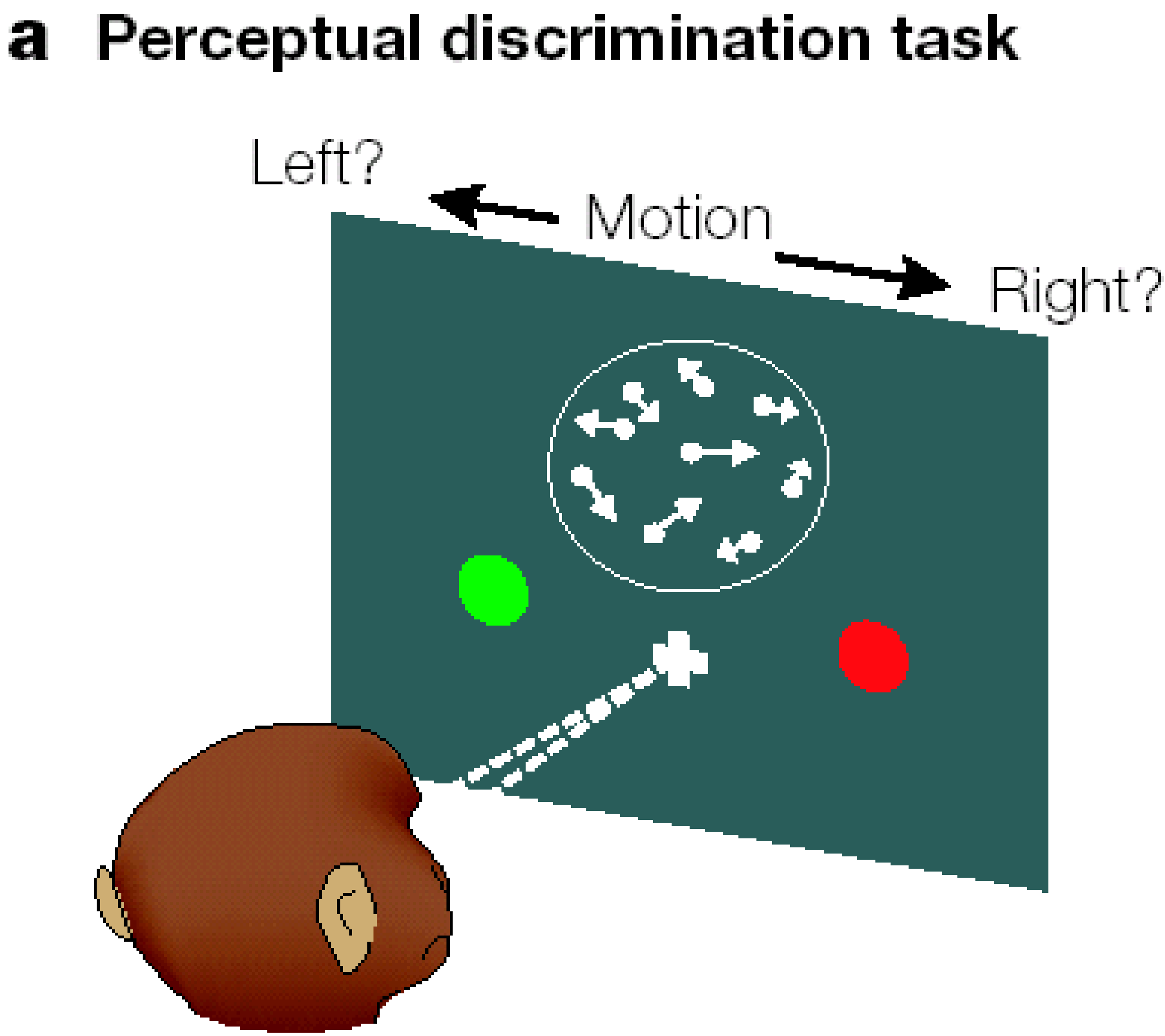
Perceptual decisions are those in which the aim of the decision-maker is to categorize ambiguous (or noisy) sensory information



Gunnar Johansson

http://www.uni-tuebingen.de/uni/knv/arl/project_learning_research_page.html





William T. Newsome

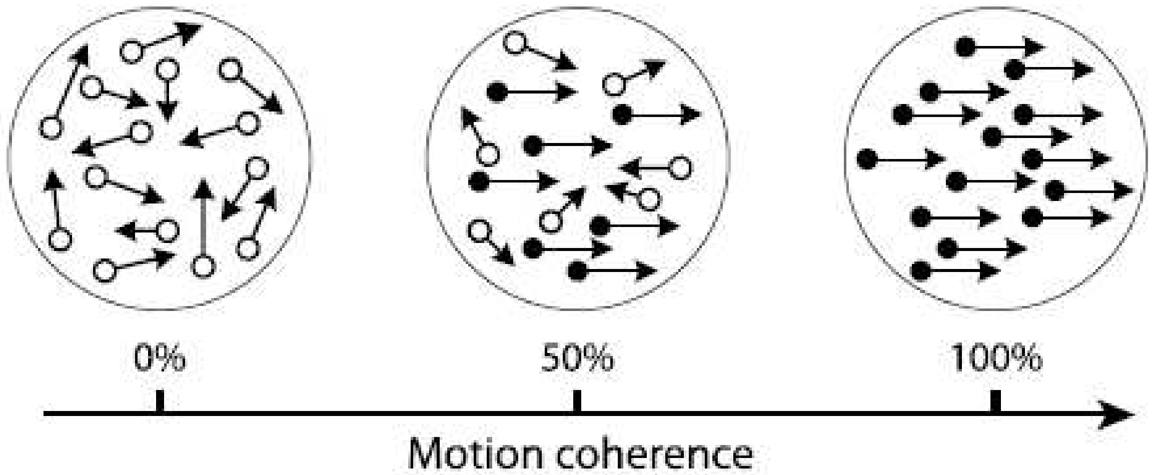
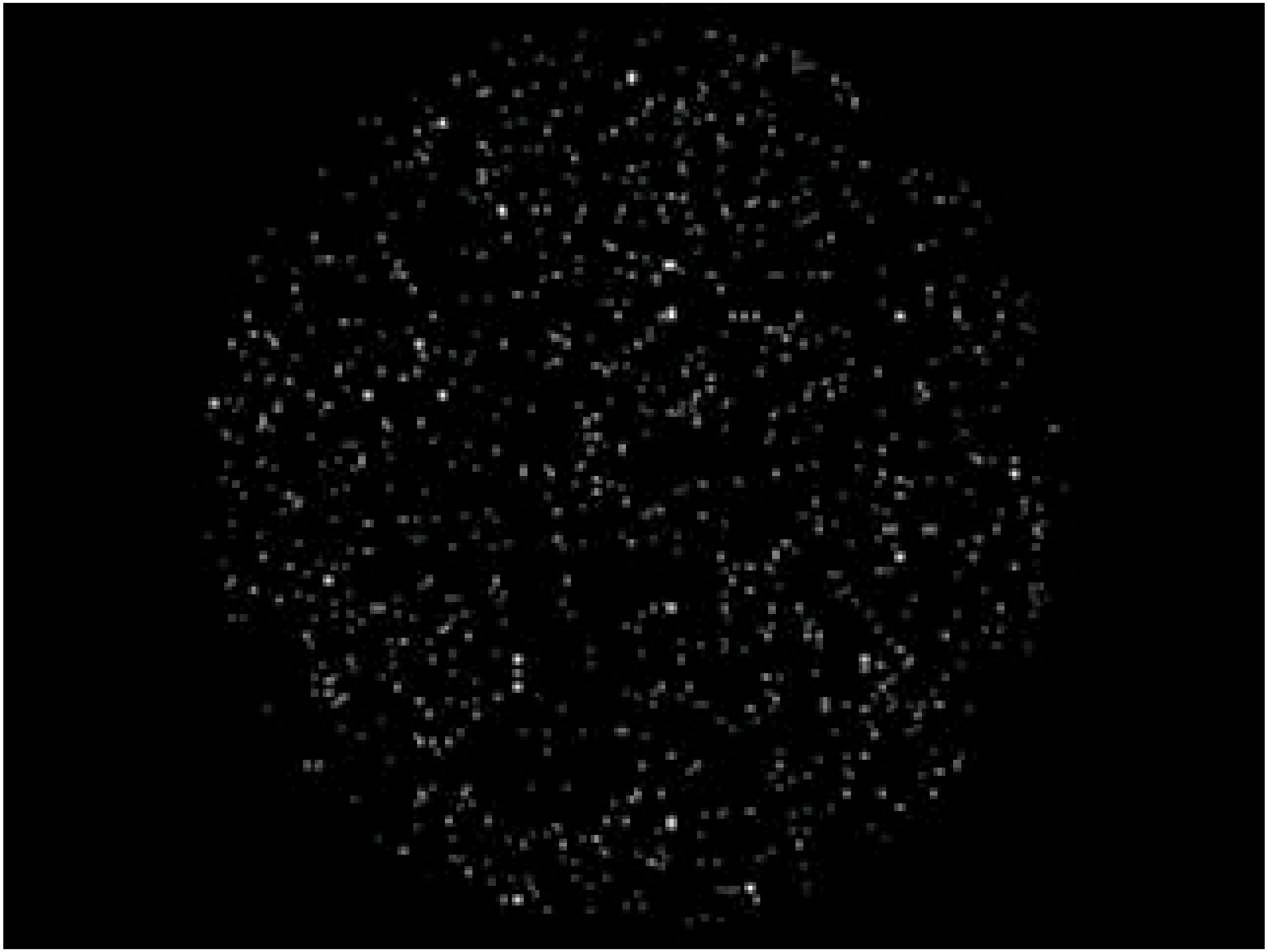


FIGURE 1 | Schematic diagram of the RDM stimulus with different motion coherence levels. In each frame a proportion of the dots (solid dots) are repositioned with fixed spatial offset, indicating the coherent motion direction, and the rest of the dots (open dots) are repositioned randomly. More detailed specification of the stimulus is available in Britten et al. (1992).

Jiaxiang Zhang ***2013***

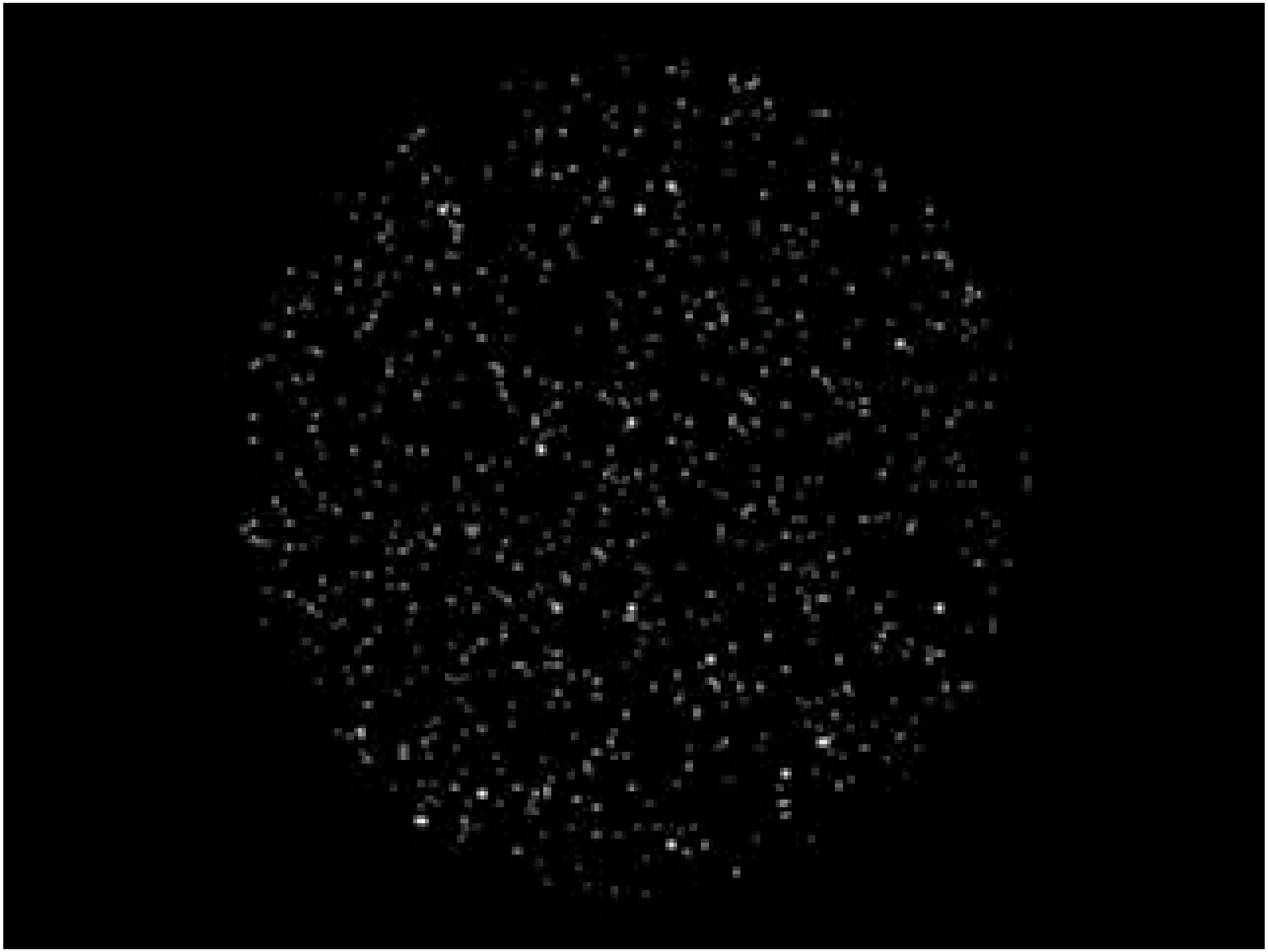
Difficult perceptual decision



100%

http://monkeybiz.stanford.edu/

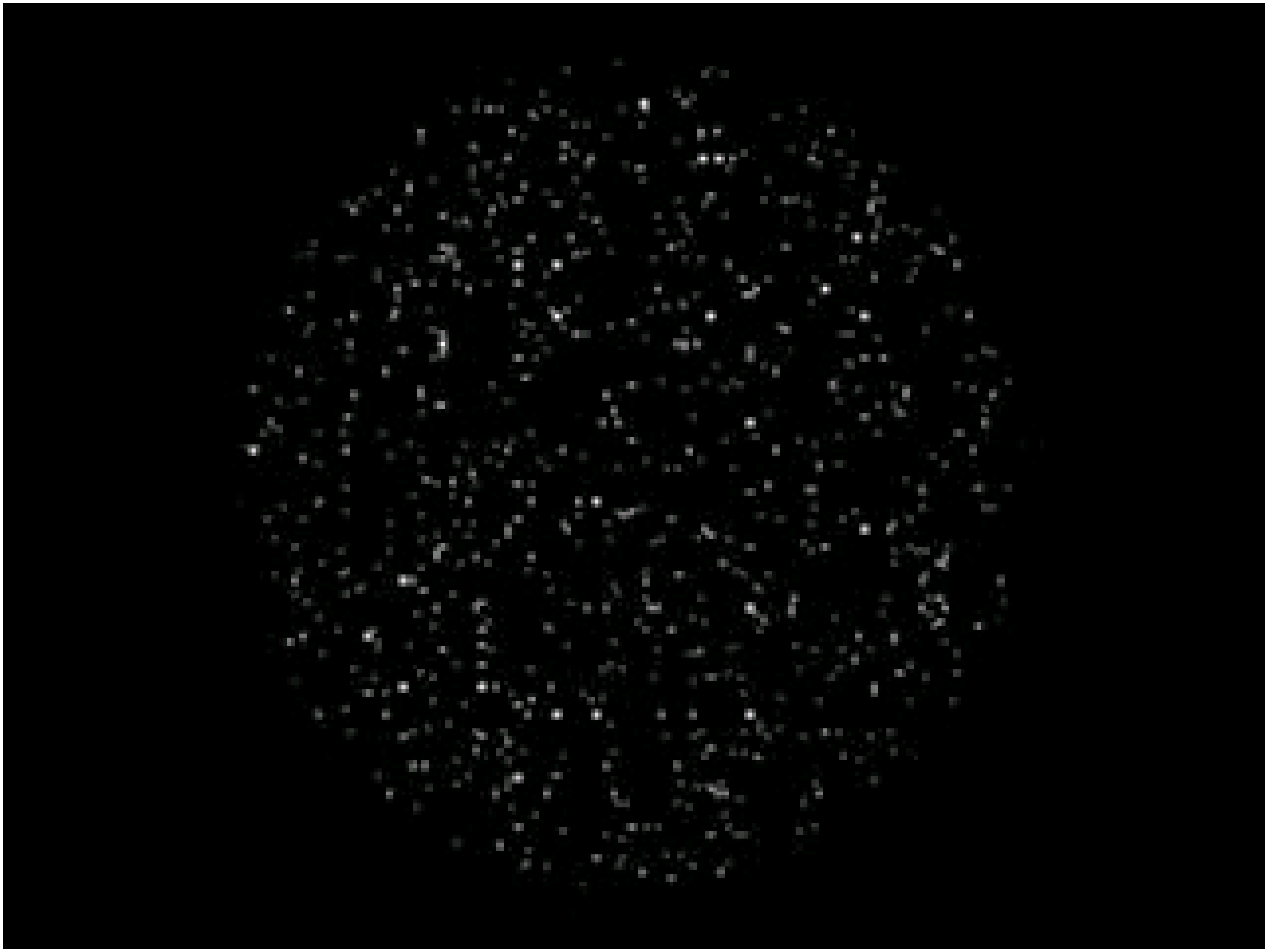
Easy perceptual decision



50%

http://monkeybiz.stanford.edu/

Very difficult perceptual decision



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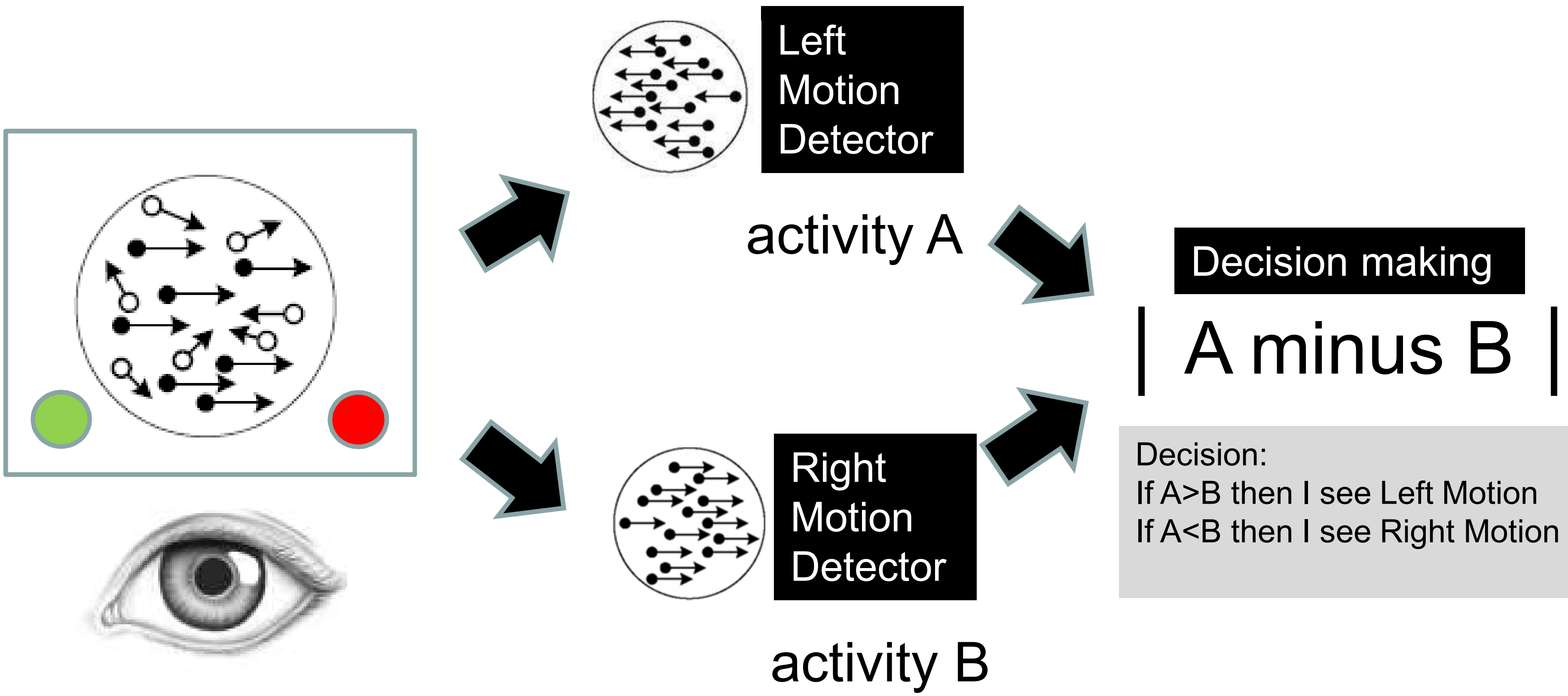
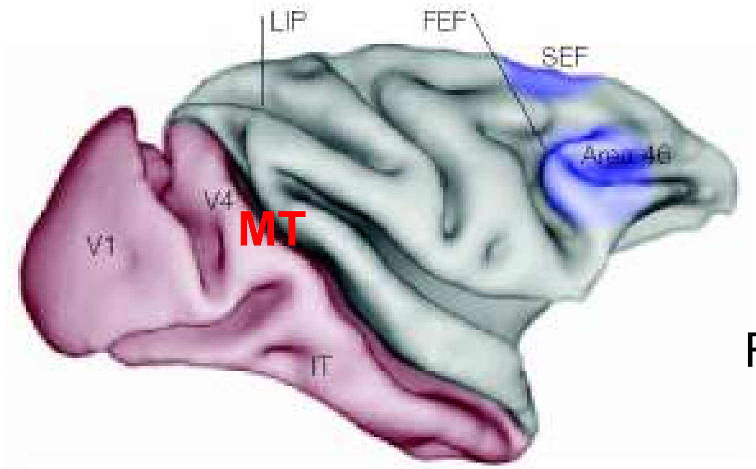
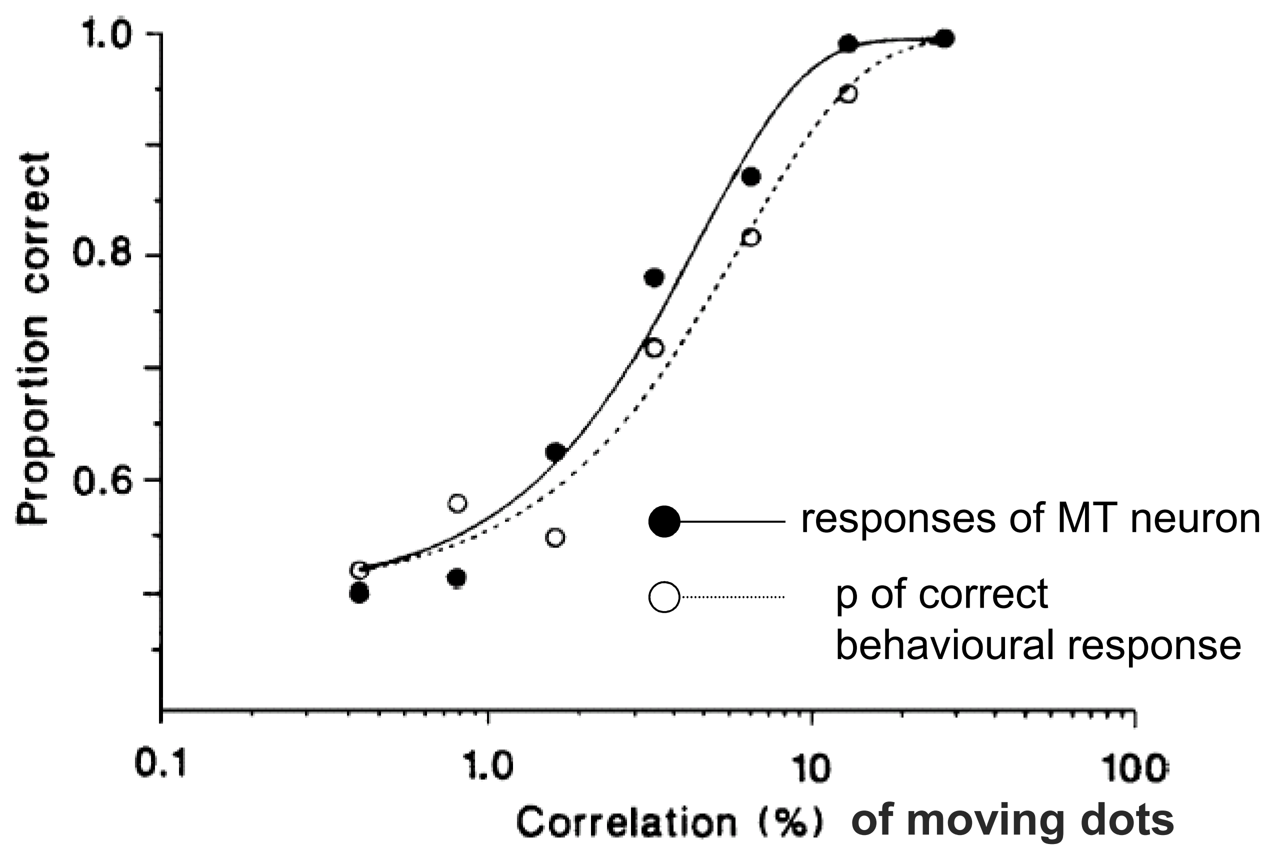
http://monkeybiz.stanford.edu/


Left
Motion
Detector
activity A
Right
Motion
Detector
activity B
Decision making
| A minus B |
Decision:
If A>B then I see Left Motion
If A<B then I see Right Motion

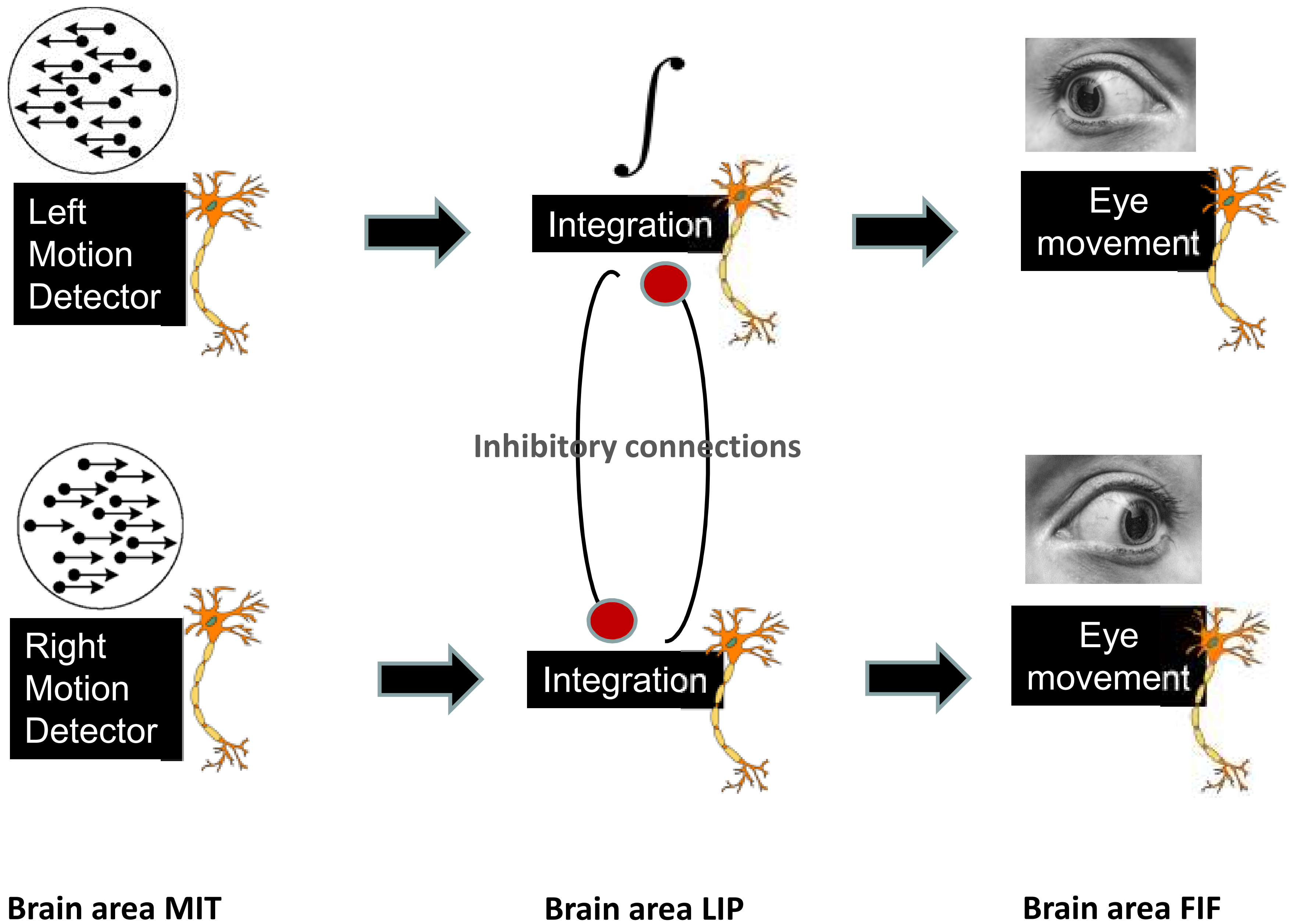


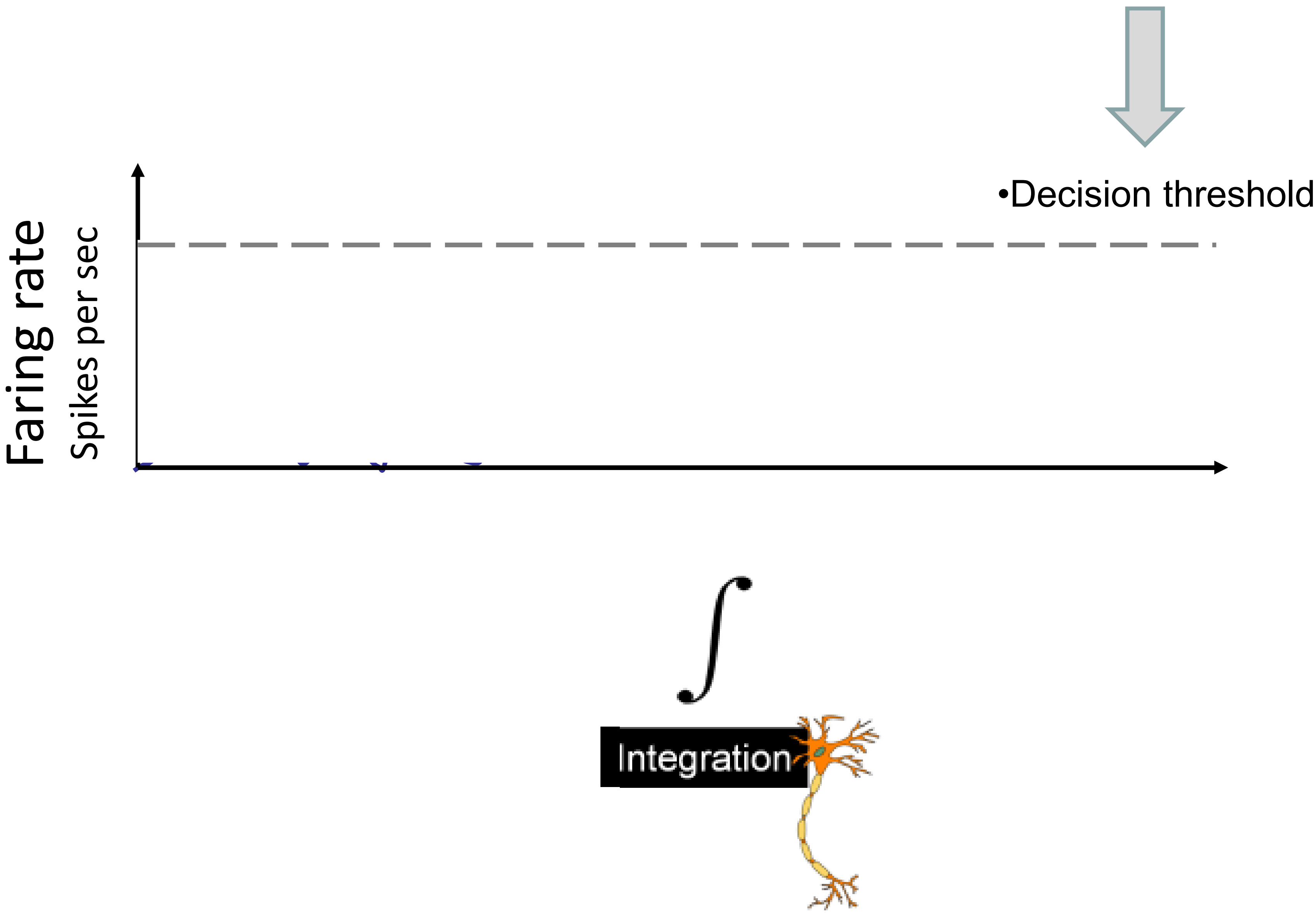
Motion Detectors – area MT

Relationship between neuronal activity and motion perception.



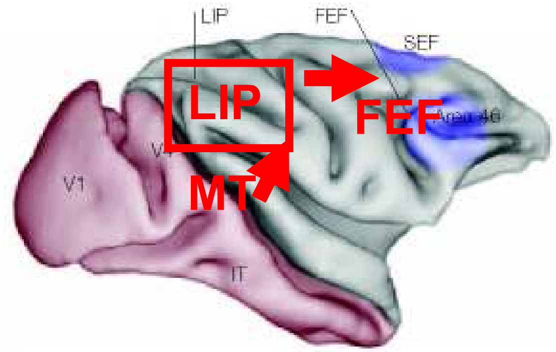
The likelihood that the monkey would make a rightward saccade was a lawful function of the firing rate of the rightward motion–preferring neurons in area MT.


Left
Motion
Detector
Integration
Eye
movement
Inhibitory connections
Right
Motion
Detector
Integration
Eye
movement
Brain area MIT
Brain area LIP
Brain area FIF

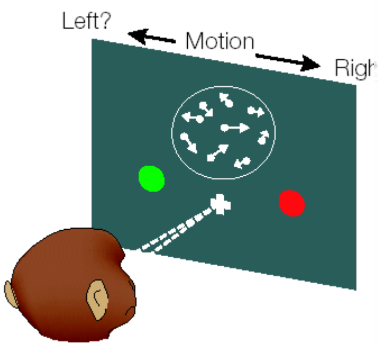


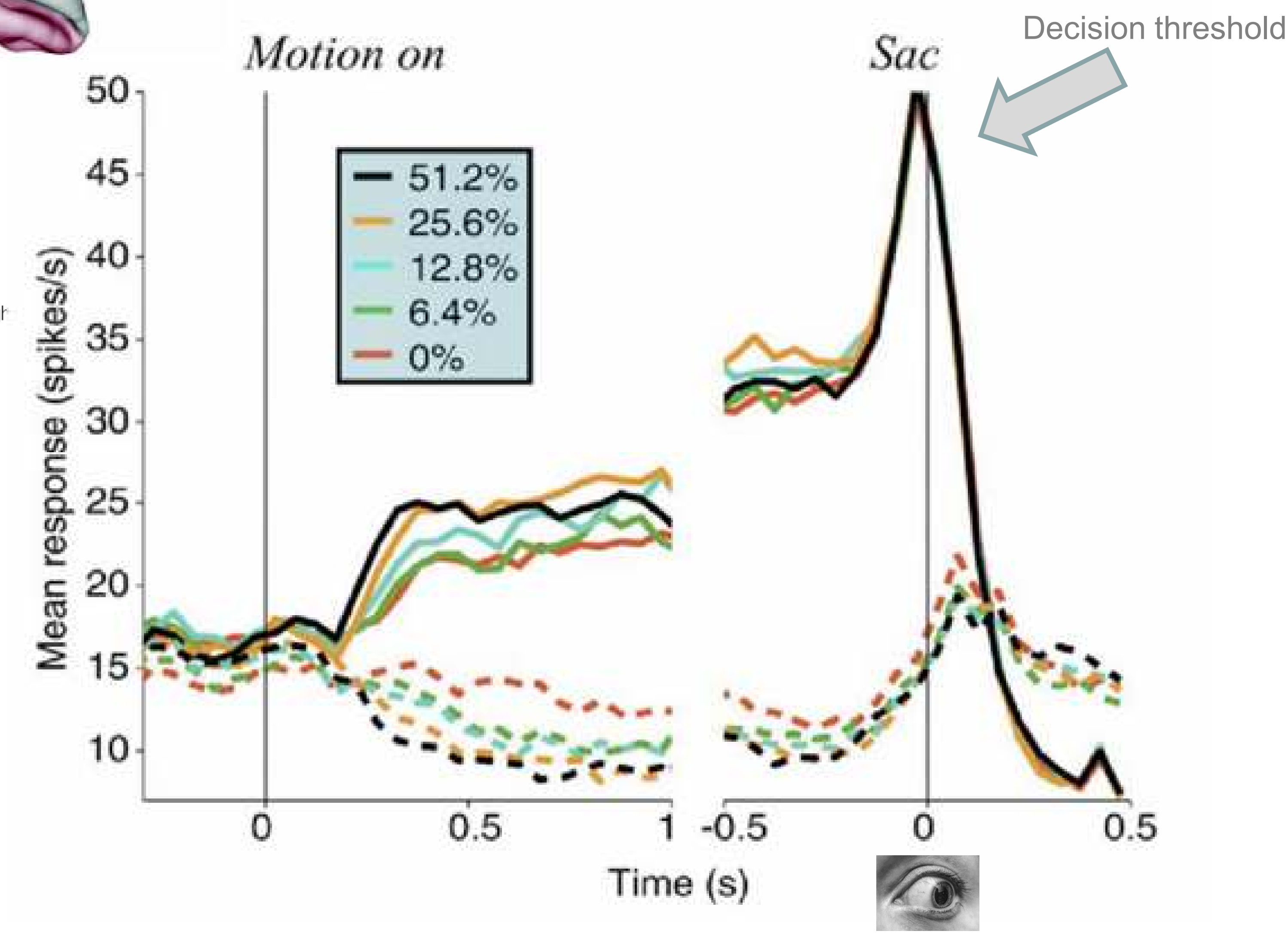
•Decision threshold
Faring rate
Spikes per sec
∫
Integration

$|$ A minus B $|$



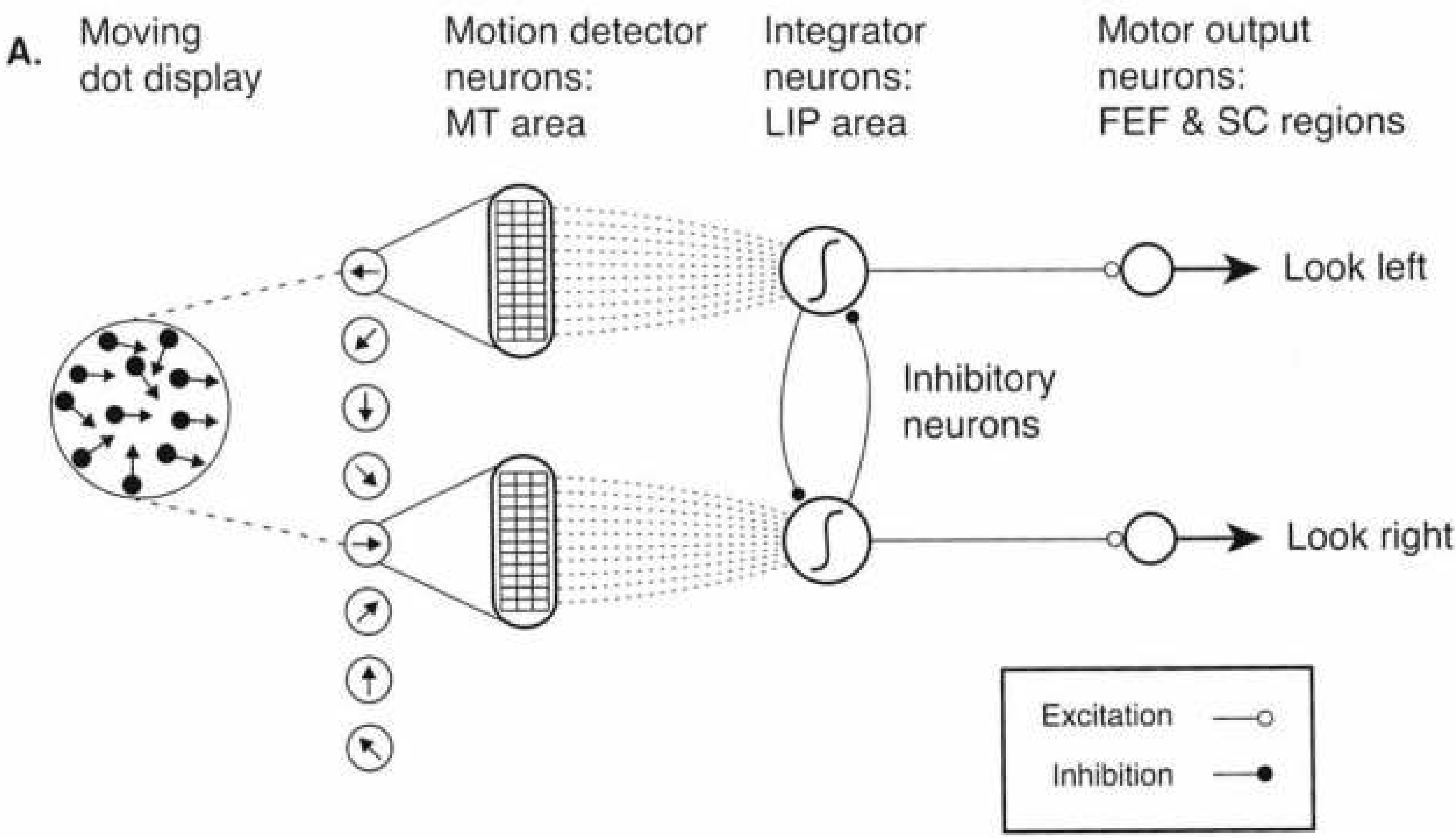
- accumulates information over time
- a decision threshold
- accounts for random decisions
- electrical stimulation affects decisions



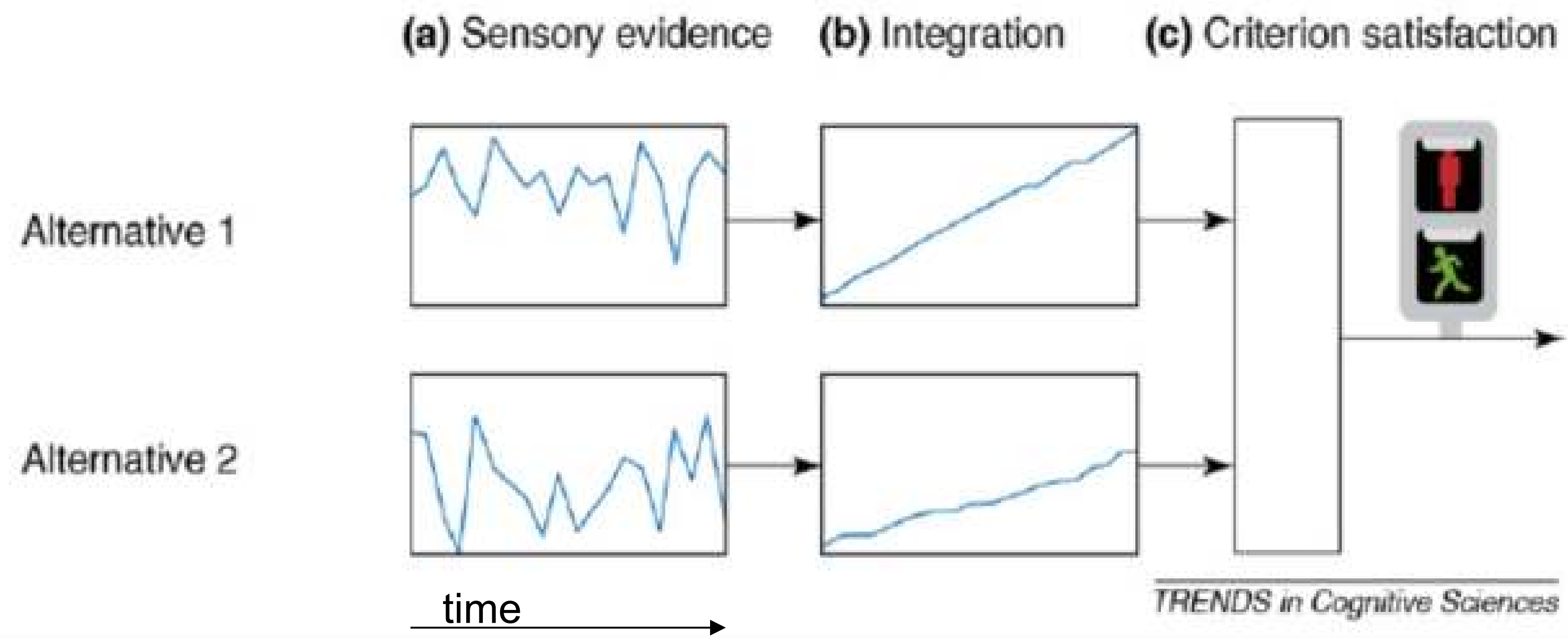


Area LIP

Perceptual decision making



Shadlen and colleagues' (1996) model of a perceptual decision circuit.

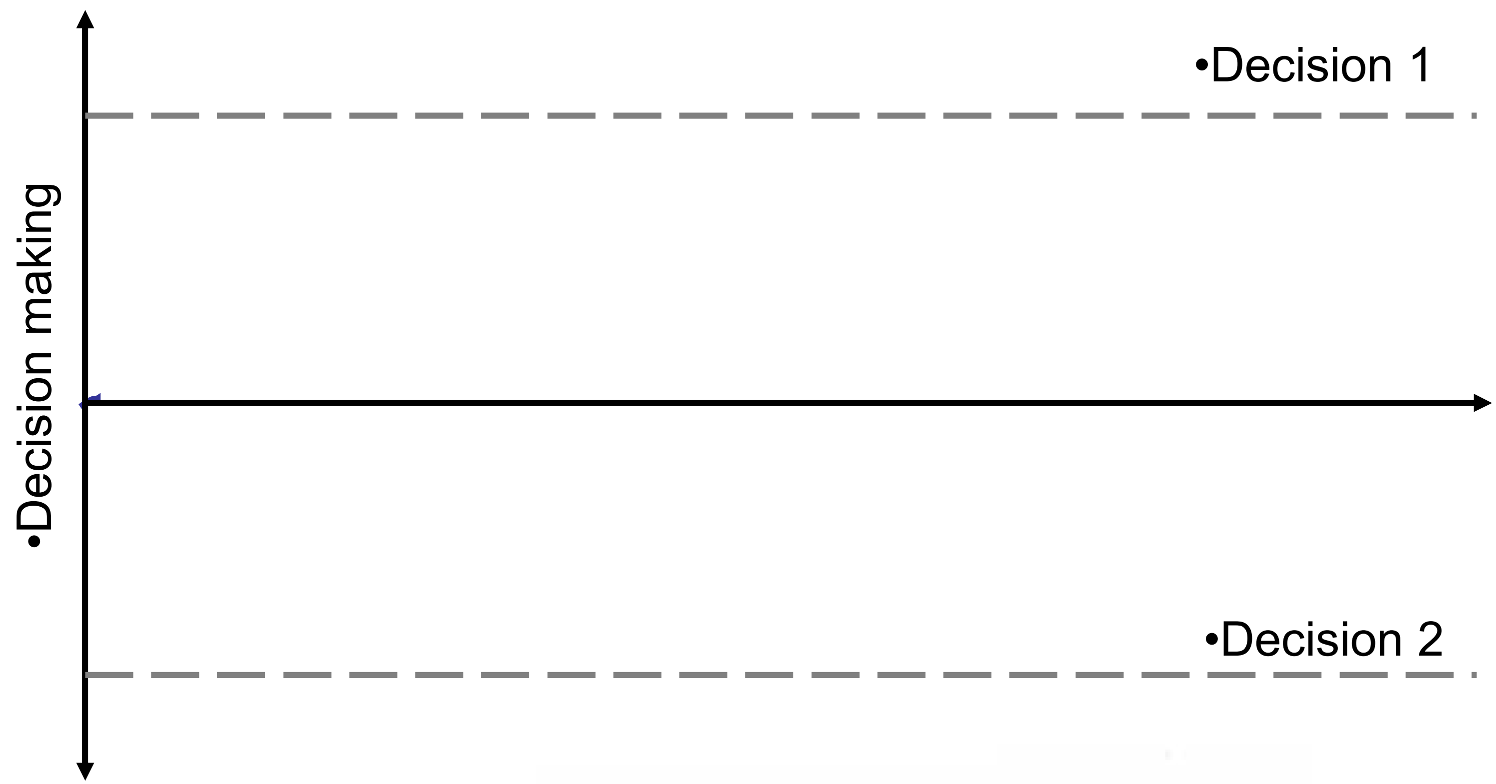


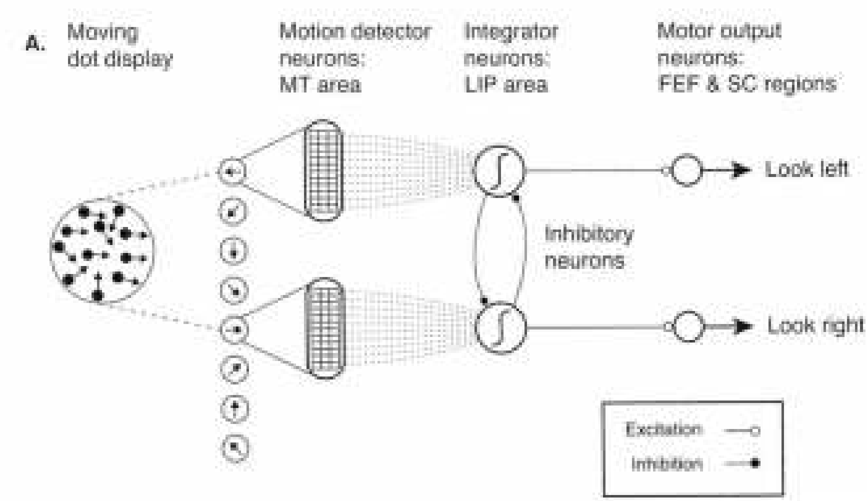
Schematic representation of decision making:

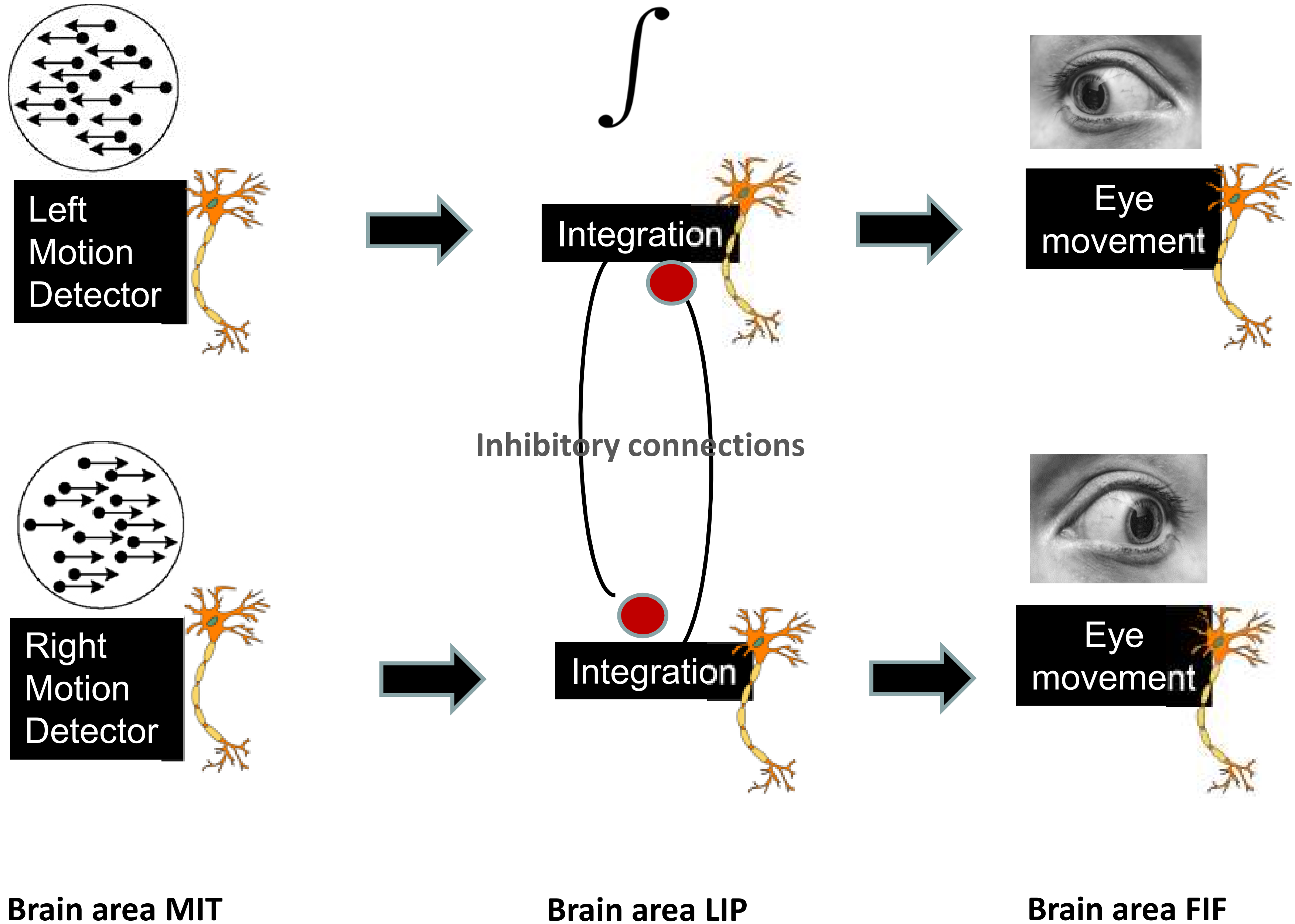
(a) **Detection** of sensory evidence to support the alternatives.

(b) **Integration** of sensory evidence over time, because the incoming evidence <u>is noisy</u>.

(c) Checking whether a certain criterion has been satisfied (e.g pass a **threshold**). It indicates if the action can be executed or if it is better to wait and continue the integration process.


•Decision 1
•Decision making
•Decision 2

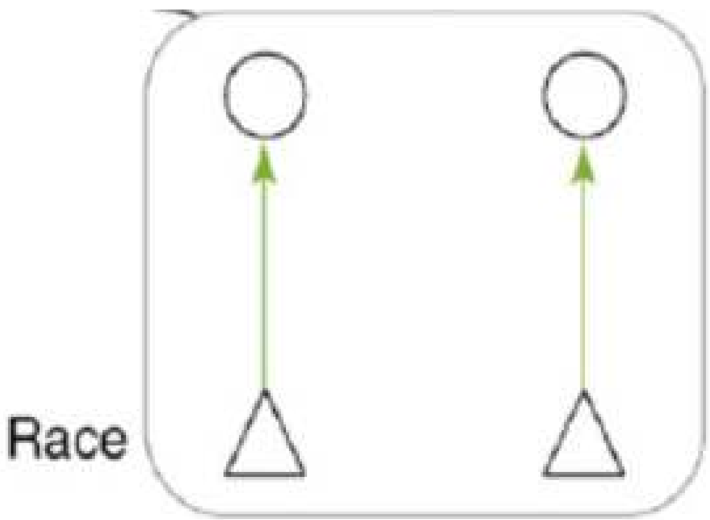

A.
Moving dot display
Motion detector neurons: MT area
Integrator neurons: LIP area
Motor output neurons: FEF & SC regions
Look left
Inhibitory neurons
Look right
Excitation
Inhibition

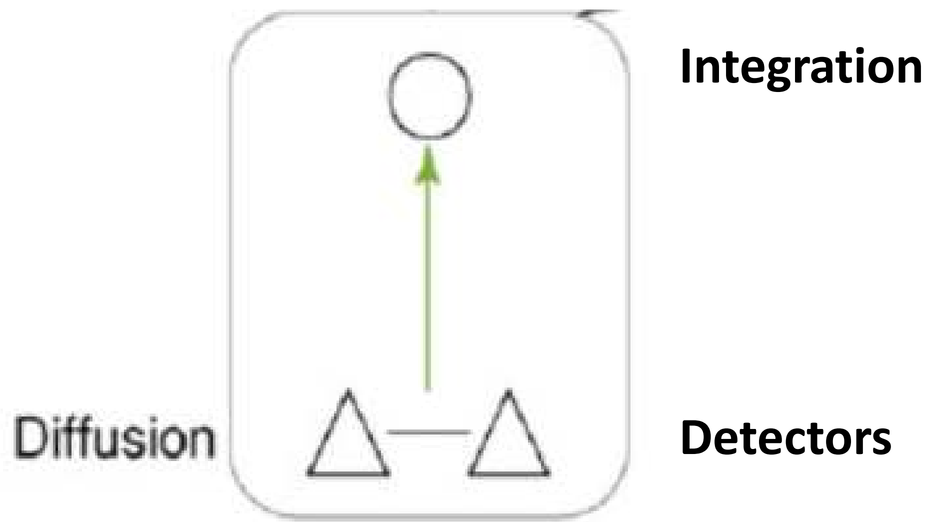


$\int$
Left Motion Detector
Integration
Eye movement
Inhibitory connections
Right Motion Detector
Integration
Eye movement
Brain area MIT
Brain area LIP
Brain area FIF

Separate integrators that accumulates the evidence for the two alternatives

Single integrator that accumulates the difference between the evidence for the two alternatives

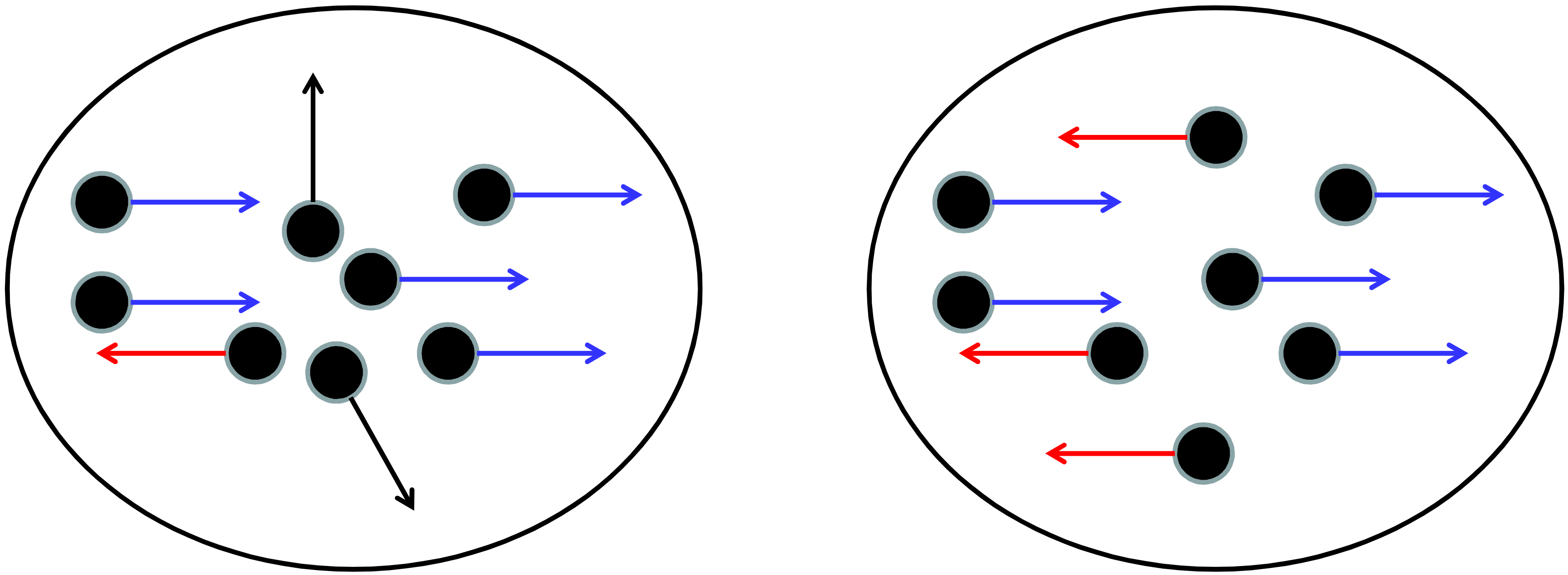




Two possible criteria of decisions

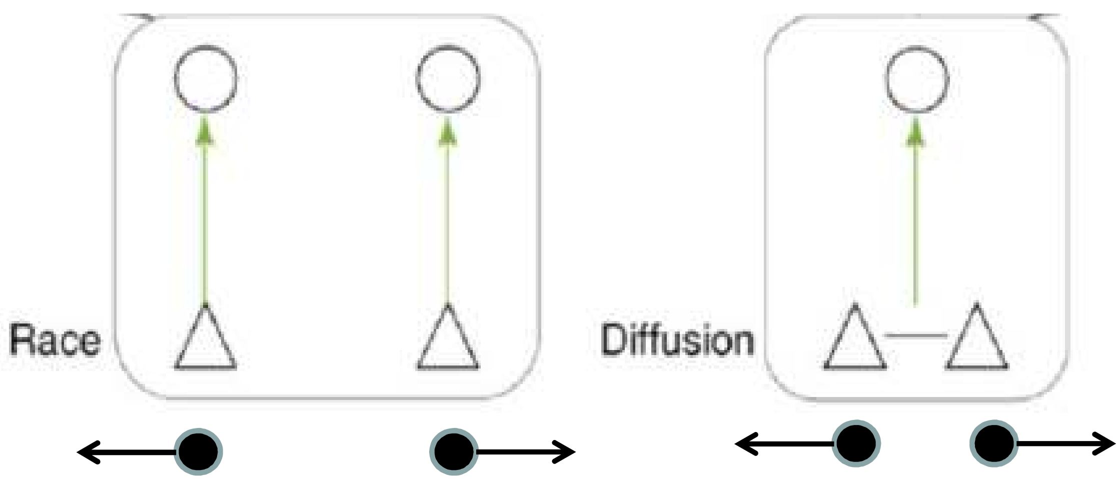
- 1st – the **'race' model** – a choice should be made as soon as the integrated evidence in support of one of the alternatives exceeds a threshold
- 2nd –the **'diffusion' model** – a choice should be made as soon as the difference between the evidence supporting the winning alternative and the evidence supporting the losing alternative exceeds a threshold

The diffusion model is usually includes just one abstract integrator that accumulates the difference between the evidence for the two alternatives; the choice is made when the level of the activity of this integrator exceeds a threshold.

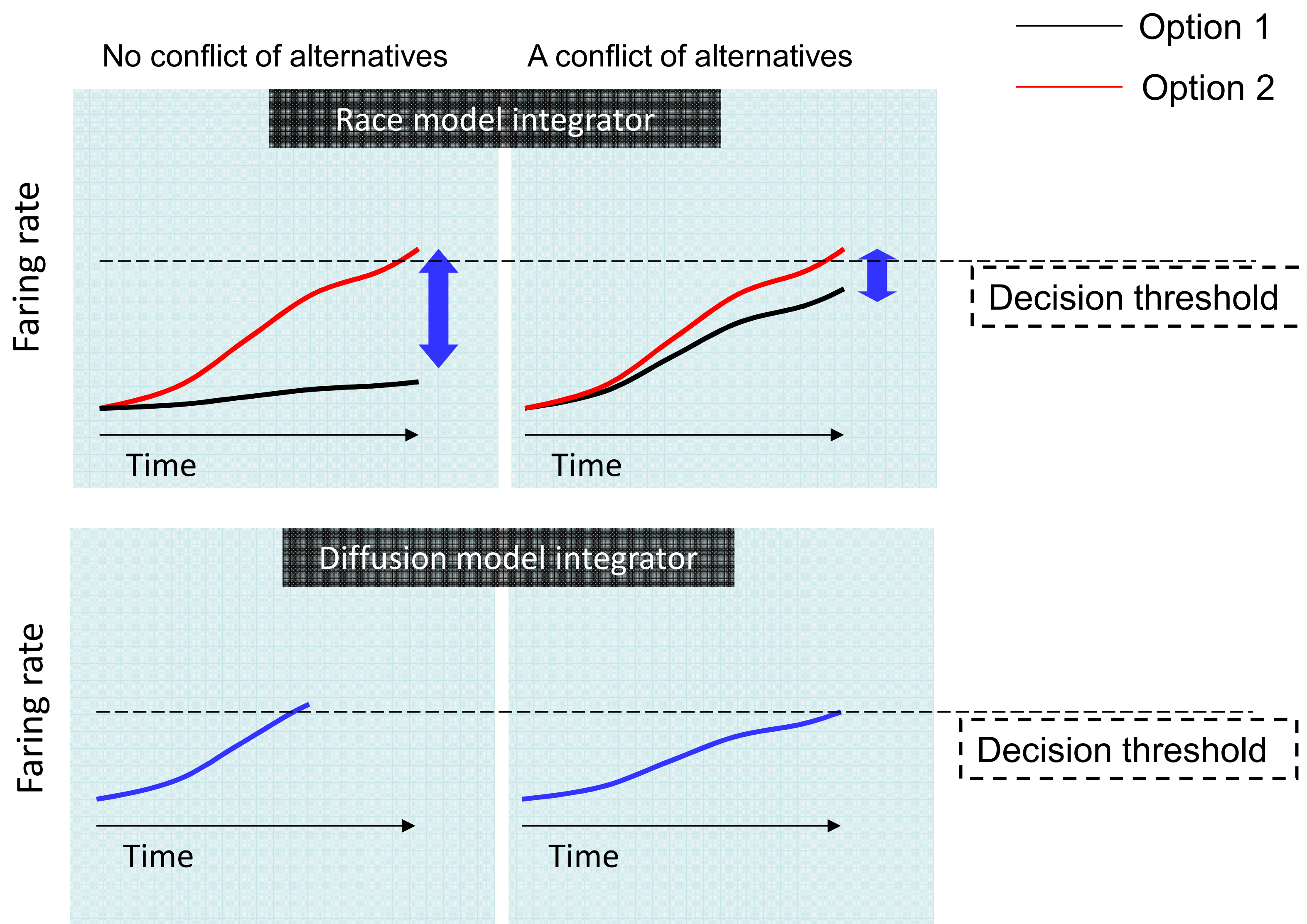


Situation 1

Situation 2



An adaptive ability is not present in the race model.

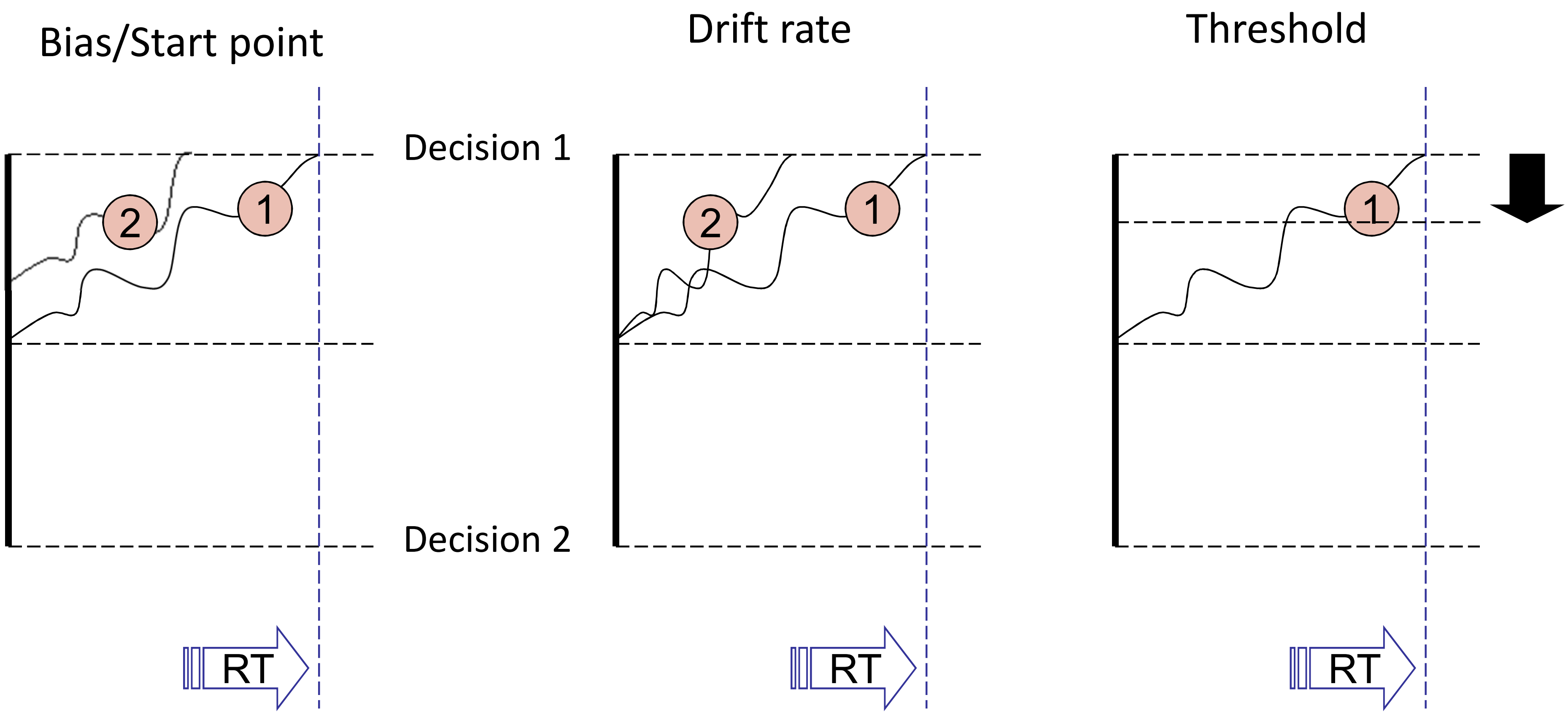


- The diffusion model reacts adaptively to the levels of evidence supporting the losing alternative: the diffusion model will integrate for a shorter time if the evidence supporting the losing alternative is weak relative to the winning alternative.

- This adaptive ability is not present in the race model.

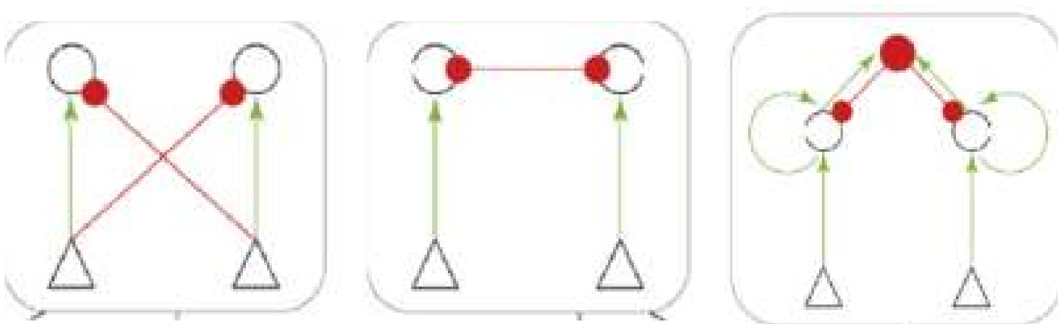
- If the thresholds in the two models are chosen to give the same accuracy, the diffusion model, on average, will be faster than the race model.

Diffusion model



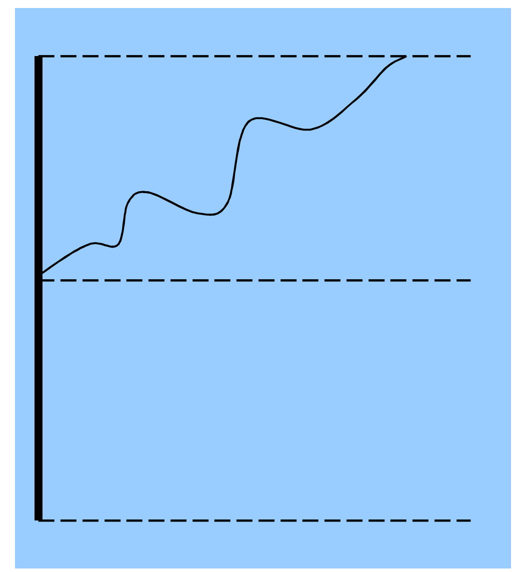
(1) Drift rate, (2) Start point, (3) Threshold

- Three **cortical** models: *Shadlen and Newsome* (SN), *Usher and McClelland* (UM) and *Wang*, to describe the cortical processes that underlie decision making.
- Each of these cortical models includes two neural integrators that correspond to the two alternatives and assumes that a choice is made as soon as the activity level in one of the integrators exceeds a threshold.

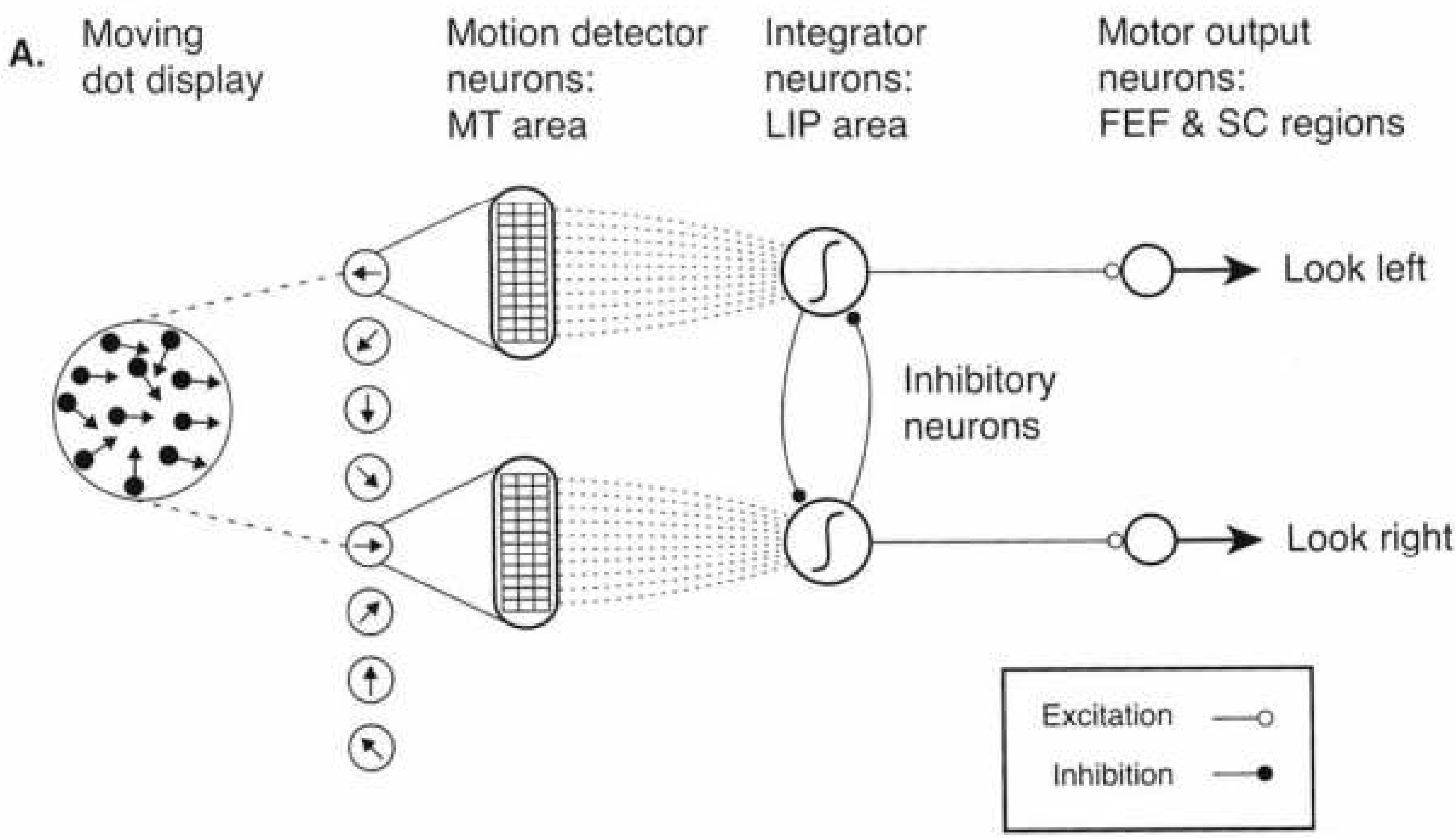


inhibitory synapses

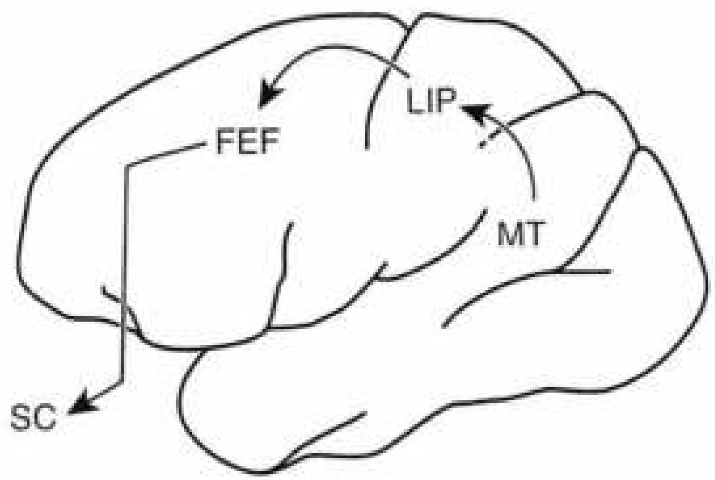
excitatory synapses



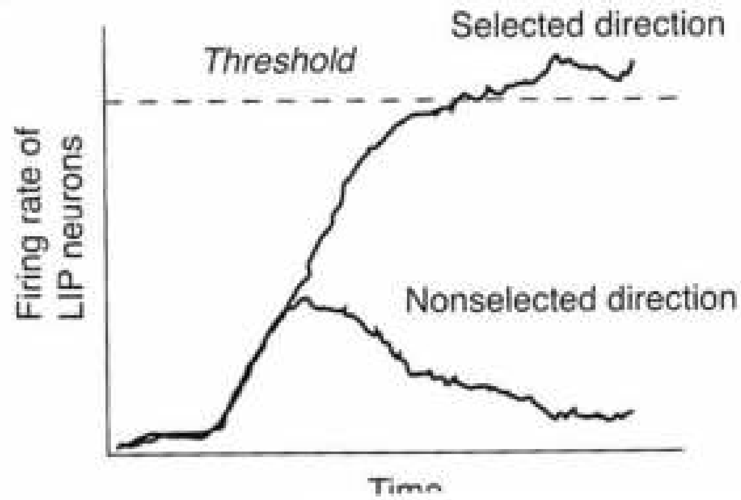
Diffusion Model

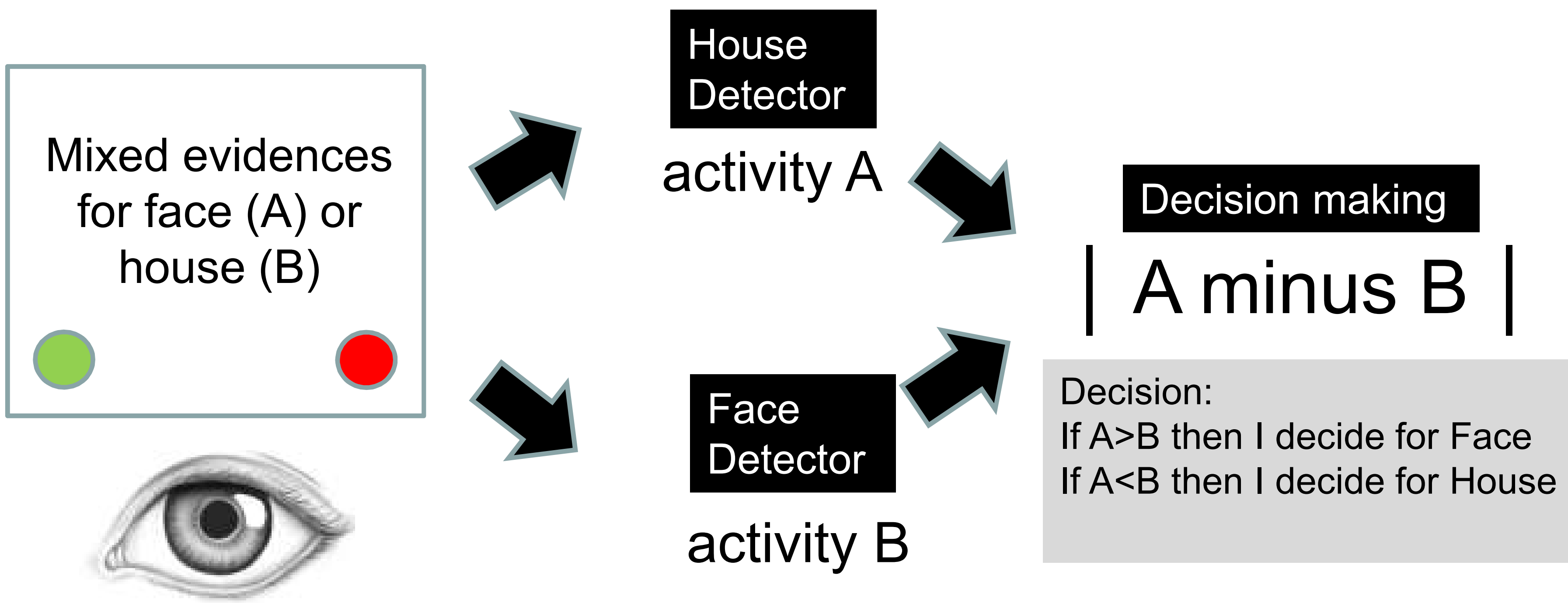

A.
Moving dot display
Motion detector neurons: MT area
Integrator neurons: LIP area
Motor output neurons: FEF & SC regions
Look left
Inhibitory neurons
Look right
Excitation
Inhibition

B.


LIP
FEF
MT
SC

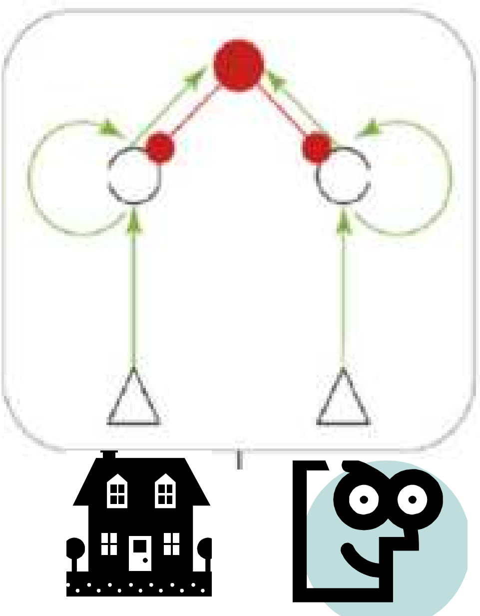
C.


Selected direction
Threshold
Firing rate of LIP neurons
Nonselected direction


Mixed evidences for face (A) or house (B)
House Detector
activity A
Face Detector
activity B
Decision making
| A minus B |
Decision:
If A>B then I decide for Face
If A<B then I decide for House

Human perceptual decisions

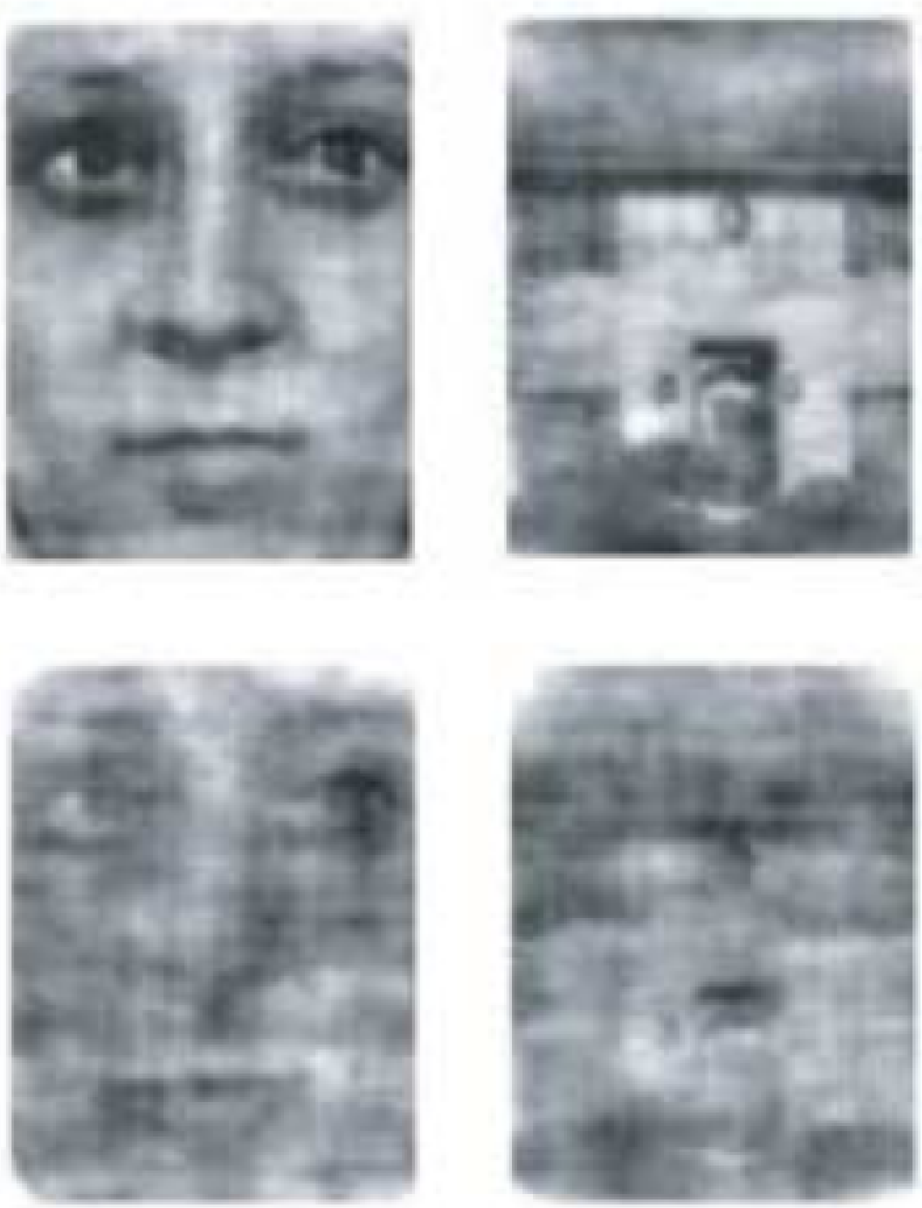
House



OR

Face

Face House



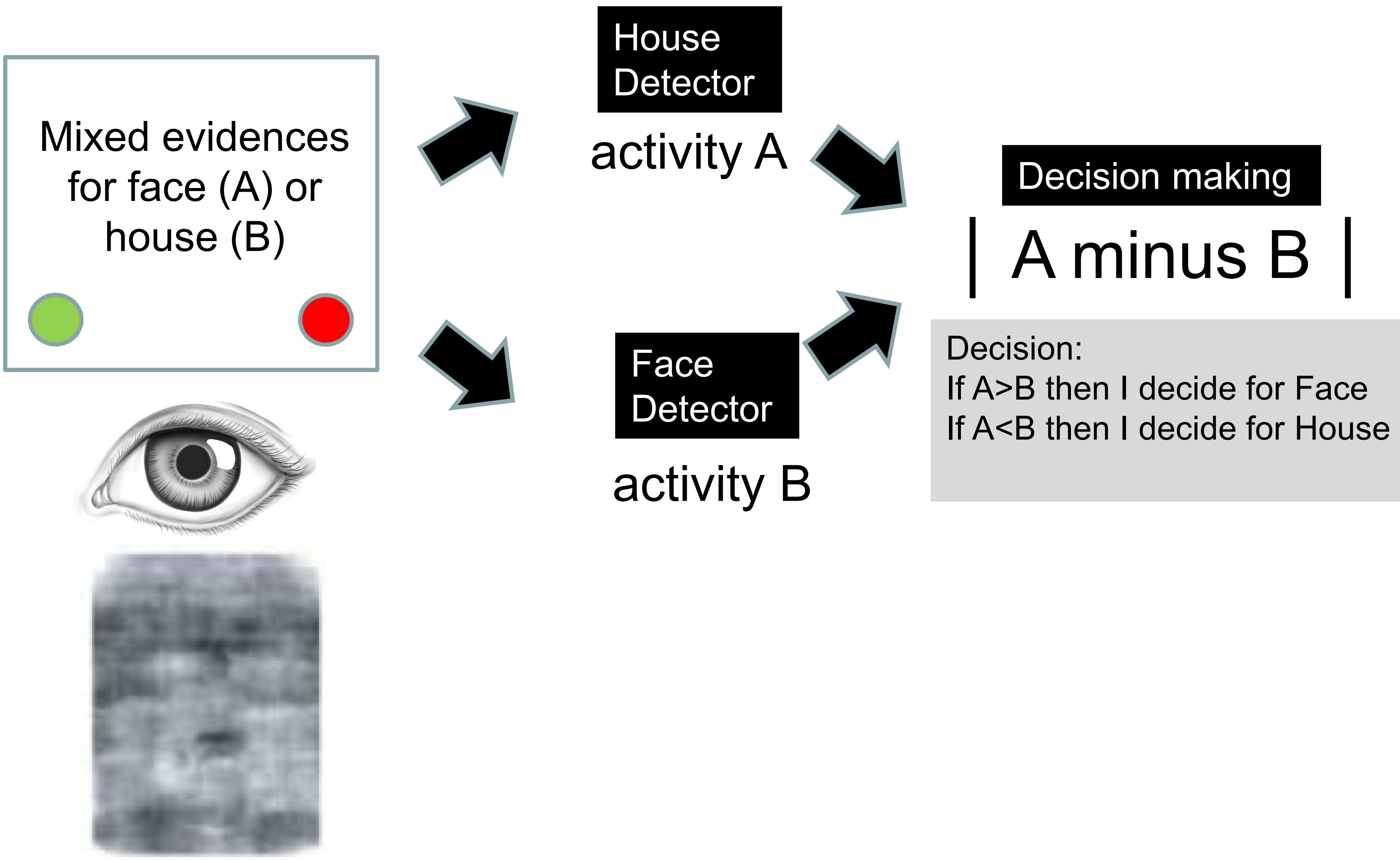
No conflict (clear picture)

A conflict (noise picture)

A general mechanism for perceptual decision-making in the human brain

H. R. Heekeren[1], S. Marrett[2], P. A. Bandettini[1,2] & L. G. Ungerleider[1]

NATURE | VOL 431 | 14 OCTOBER 2004


Mixed evidences for face (A) or house (B)
House Detector
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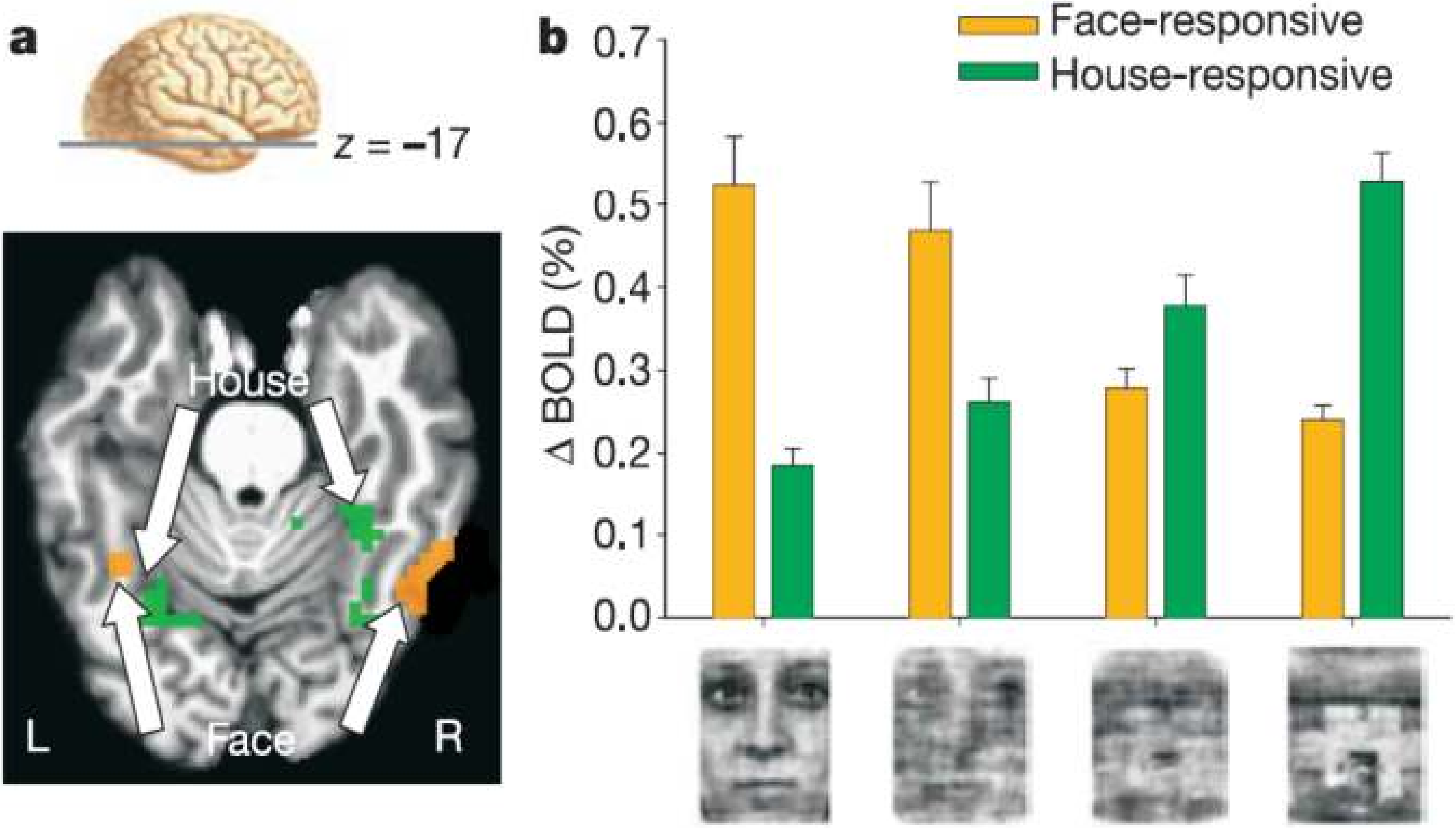
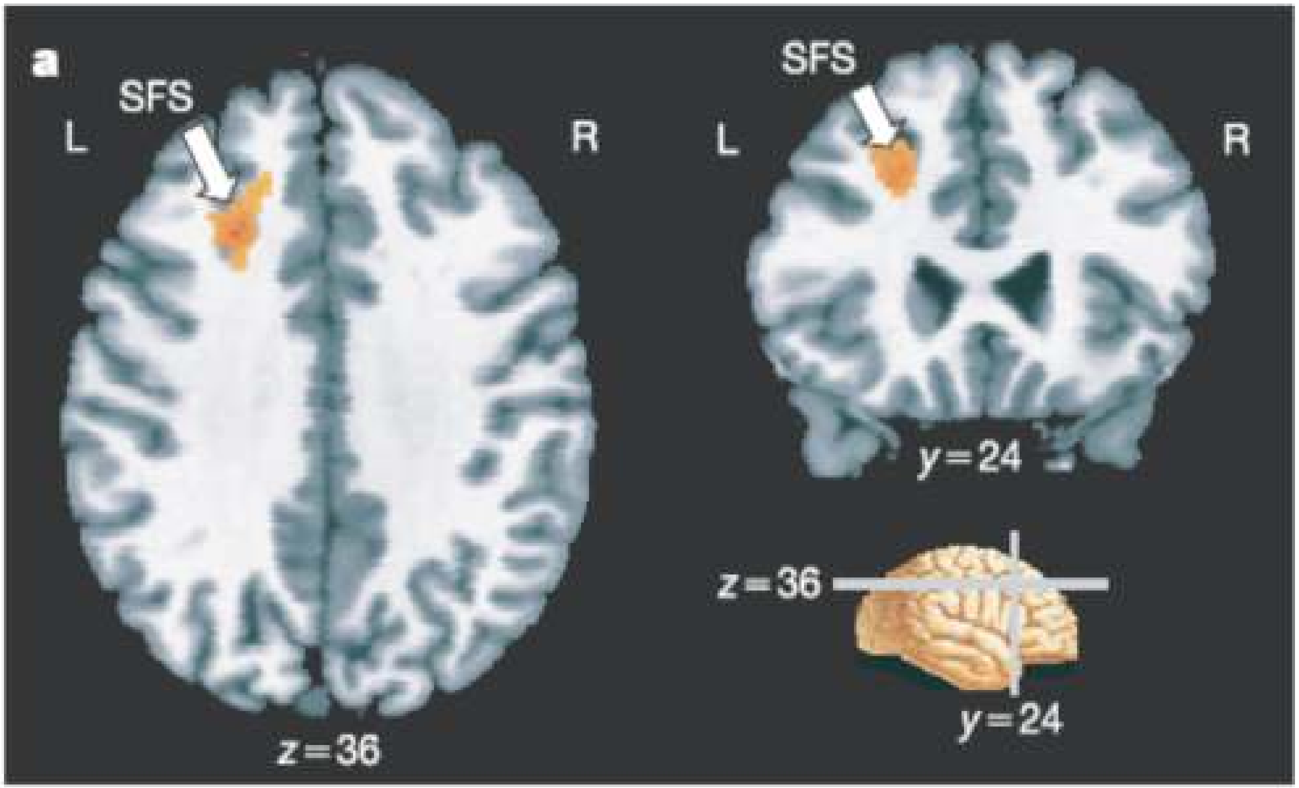
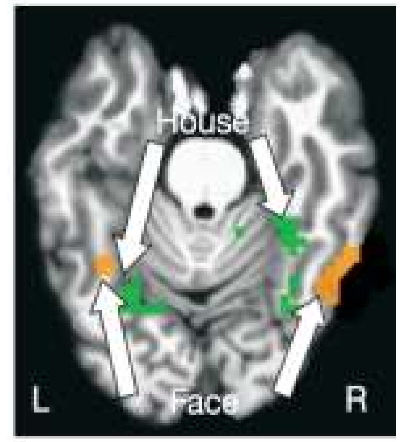

a
z = −17
House
Face
L
R
b
Face-responsive
House-responsive
Δ BOLD (%)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

Search for diffusion model integrator:



$|$**Face(t) – House(t)**$|$



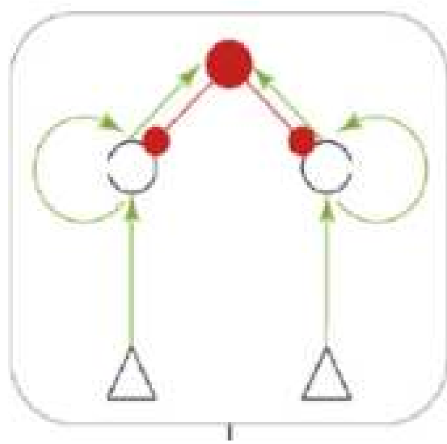
Perceptual decision-making in posterior **DLPFC**. The DLPFC shows both a higher response to clear images of faces and houses relative to noise images, and a correlation with $|$**Face(t) – House(t)**$|$, suggesting that this brain region integrates sensory evidence from sensory processing areas to make a perceptual decision

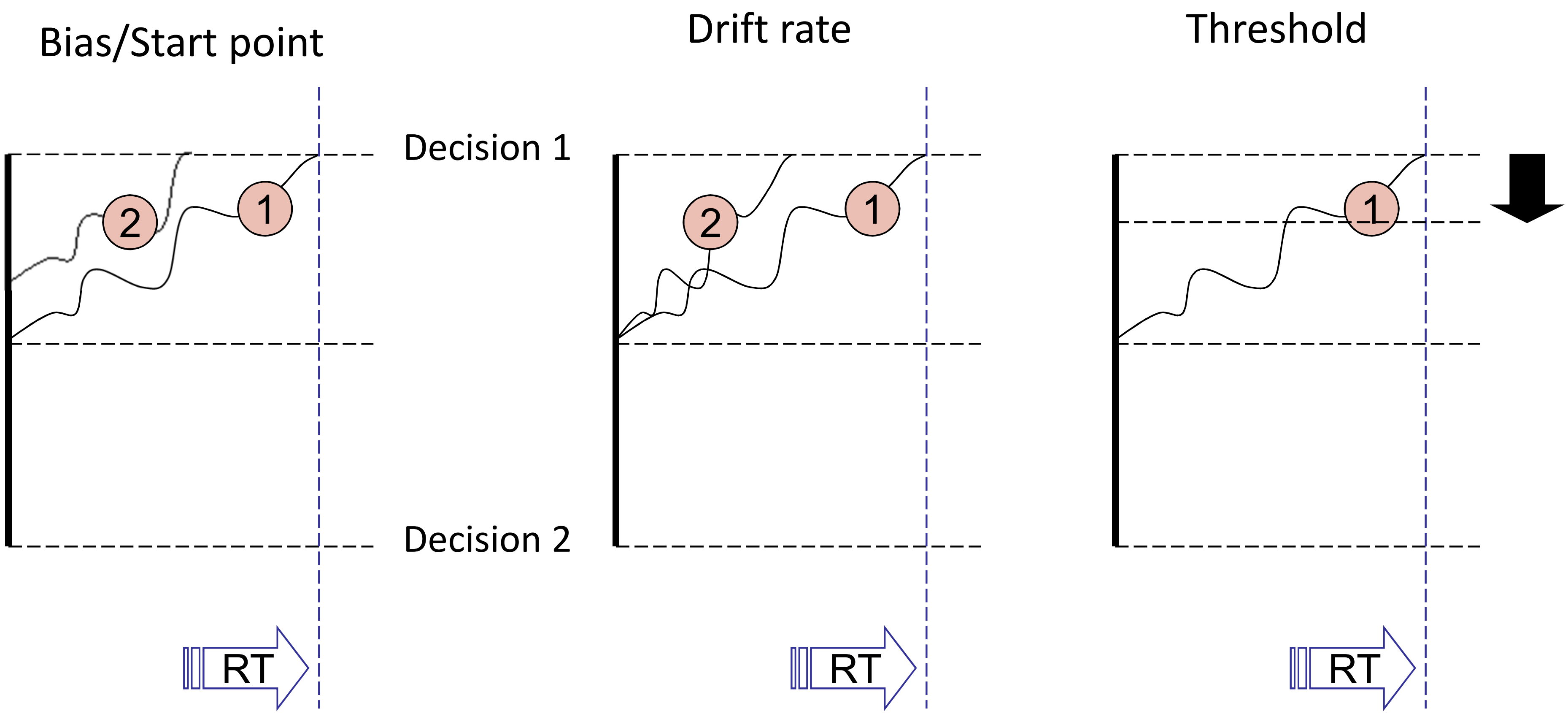
Diffusion model

(a) Left DLPFC = $\left| \text{Face}(t) - \text{House}(t) \right|$

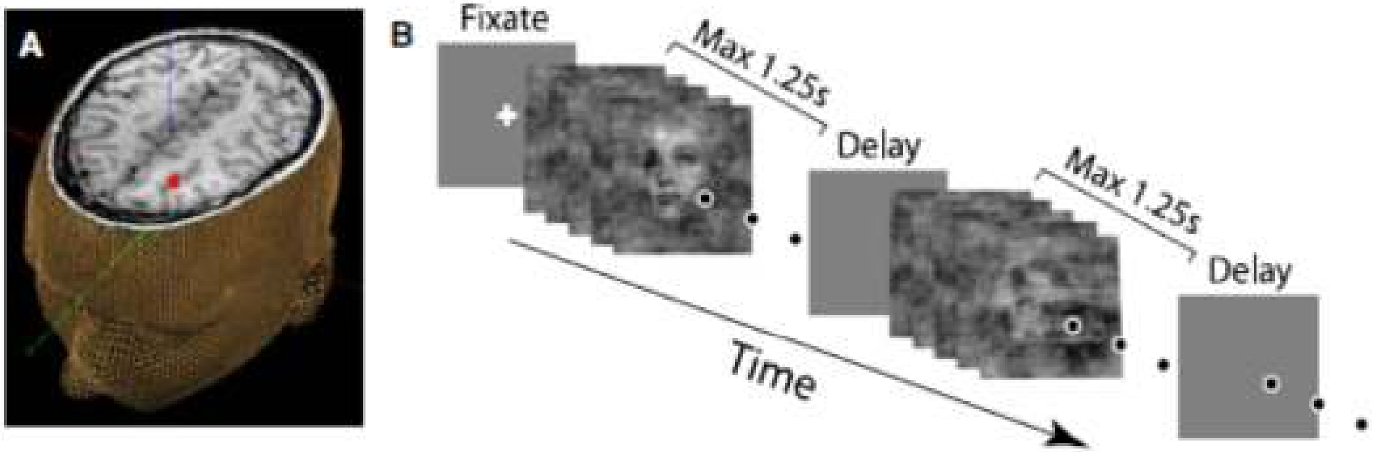
(b) DLPFC predicts behavioral performance.

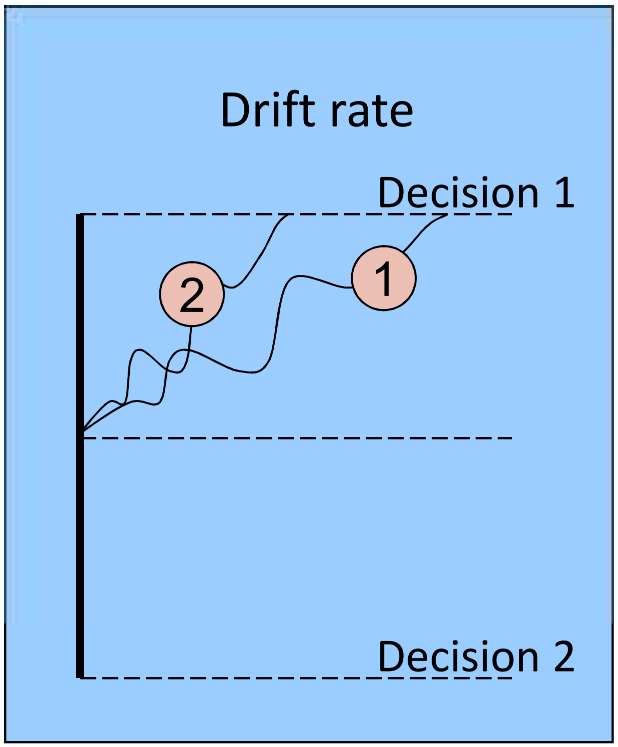
The comparison of the outputs **the diffusion model** could be a general mechanism by which the human brain computes decisions.

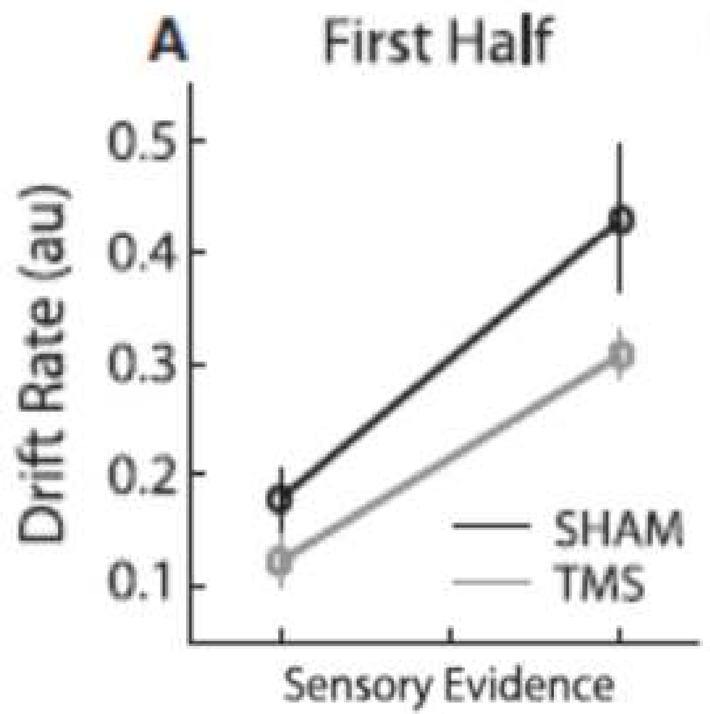




(1) Drift rate, (2) Start point, (3) Threshold







Philiastides et al, 2011 Current Biology

Take-home message

- ✓ The ‘diffusion’ model: choice should be made as soon as the difference between the evidence supporting the winning alternative and the evidence supporting the losing alternative exceeds a threshold
- ✓ **Nervous system can actually perform ‘diffusion’ model-like calculations.**

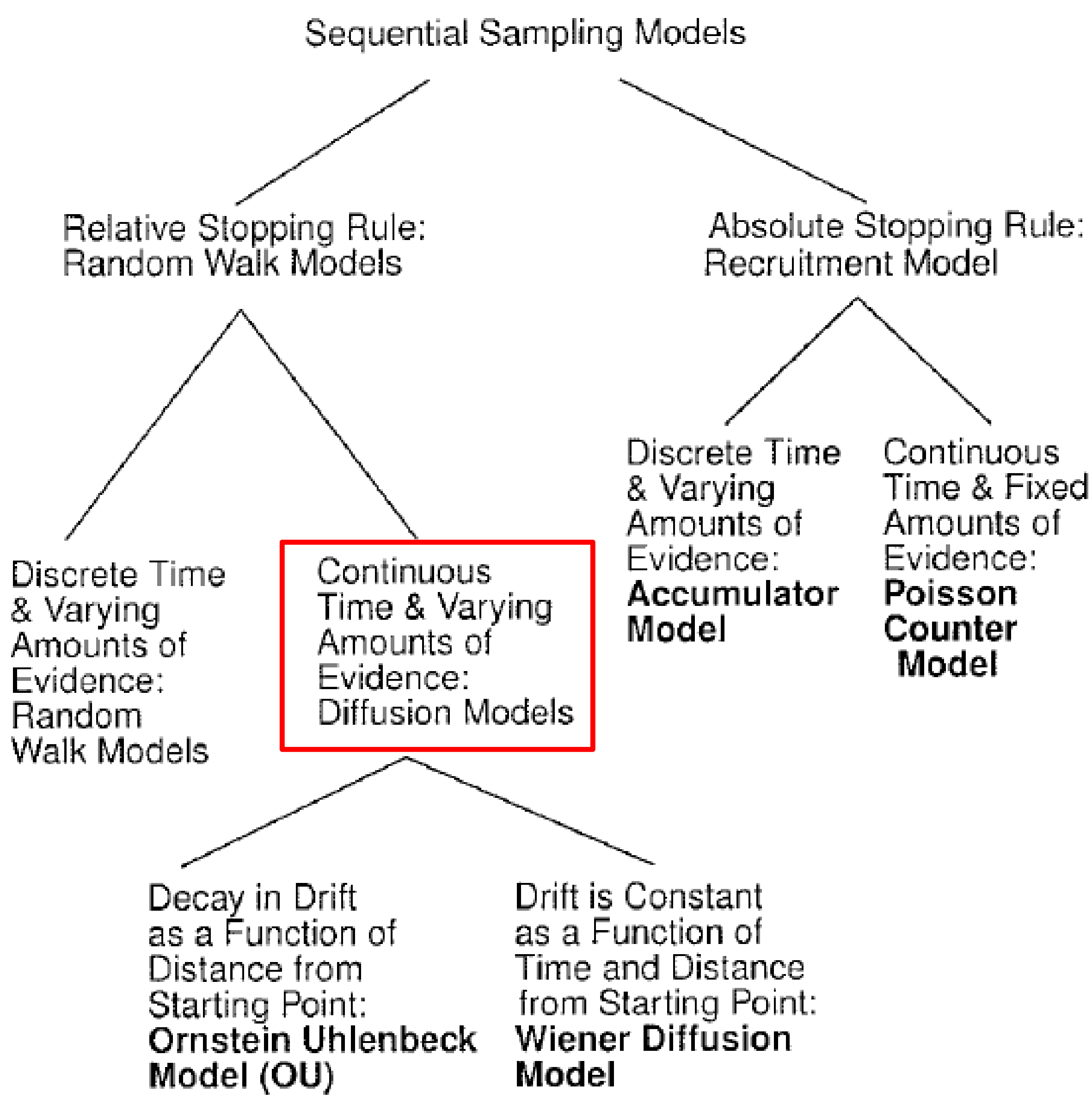


Figure 1. The relationship between the various stochastic reaction time models. The models evaluated in this article are in bold.

Psychological Review
2004, Vol. 111, No. 2, 333–367

Additional perspectives

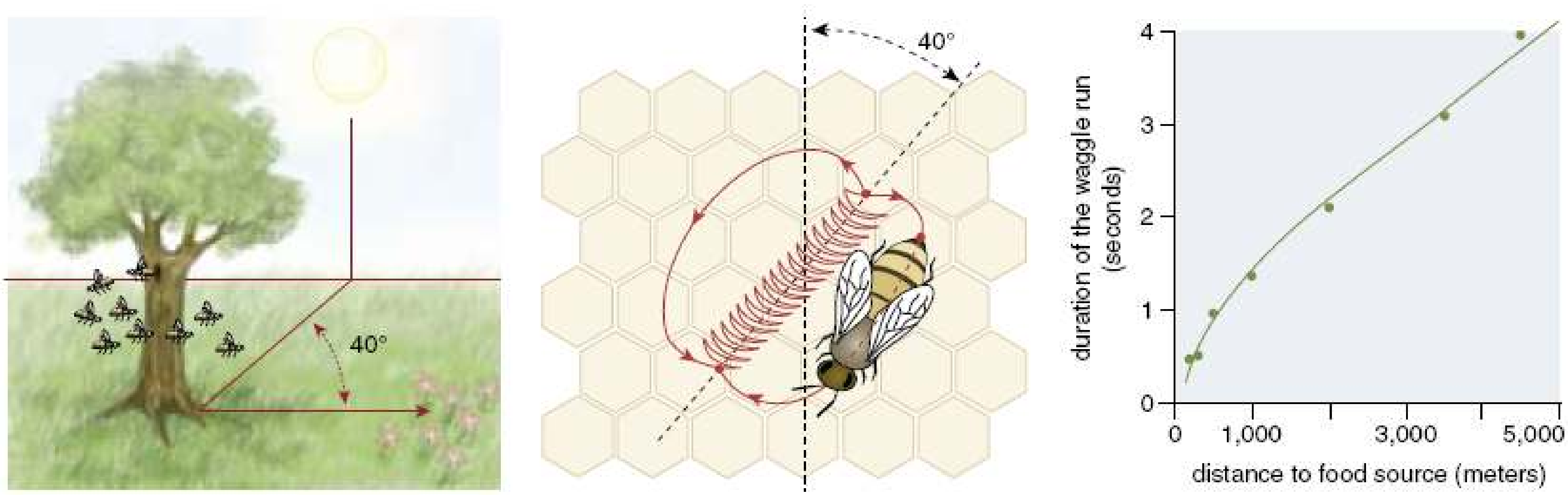
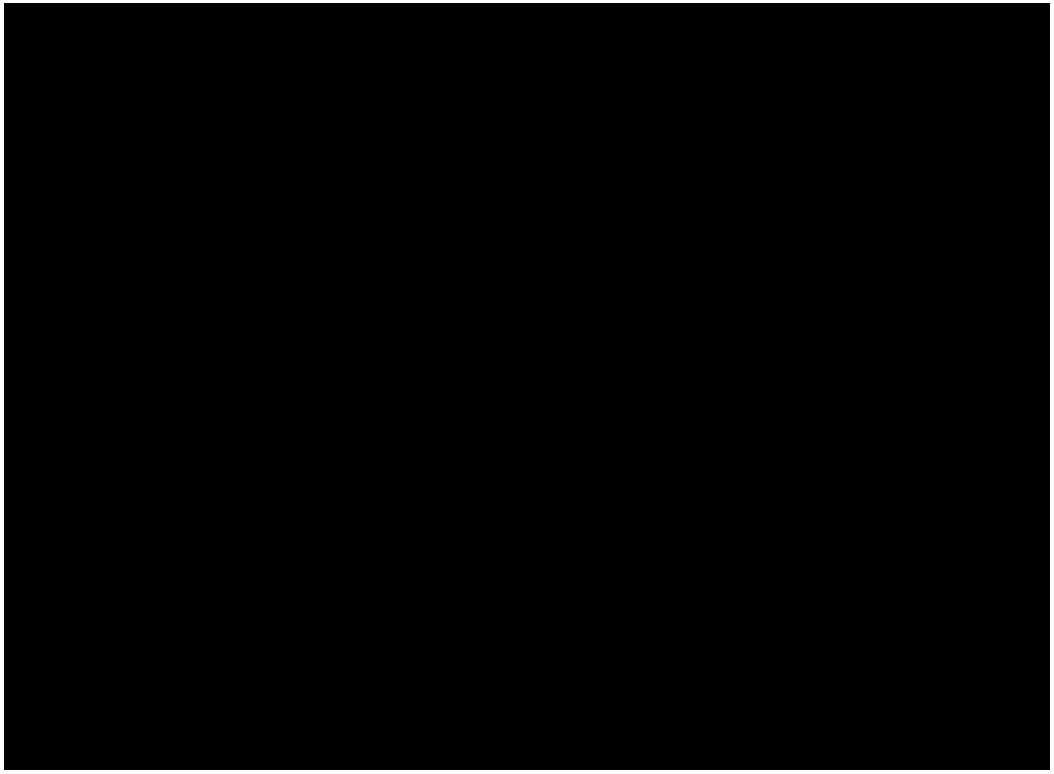


Figure 3. Honey bees employ waggle dances to inform others about food sources, as shown here, but the same dances are also used to describe the location of nest sites. Here, flowers lie along a line 40 degrees to the right of the Sun as the bees leave their nest *(left)*. To report this food source, a bee runs through a figure-eight pattern on a vertical comb *(center)*. As she passes through the central portion of the dance, she performs the *waggle run*, vibrating her body laterally, and the angle of the run indicates the direction to the food source. The duration of the waggle run relates to the distance to the food source *(right)*. When waggle dancing refers to nest sites, it occurs on the surface of a swarm rather than on the combs inside a hive.

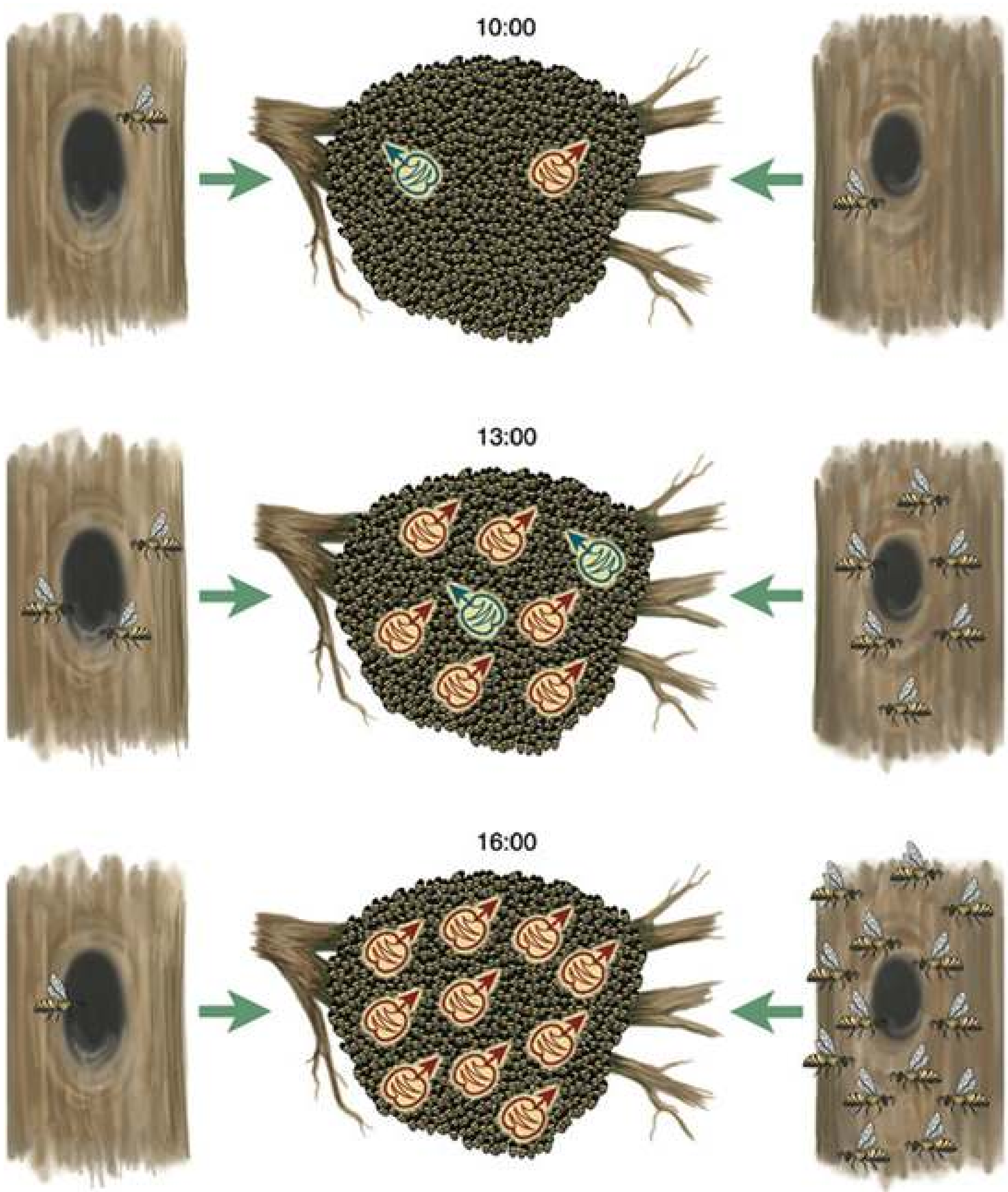
Bee Dance (Waggle Dance)



Bienentanz Gesellschaft für Kommunikation mbH in Berlin, Germany (www.bienentanz.com).

Seeley et al (2006)

Additional perspectives



Seeley et al (2006)

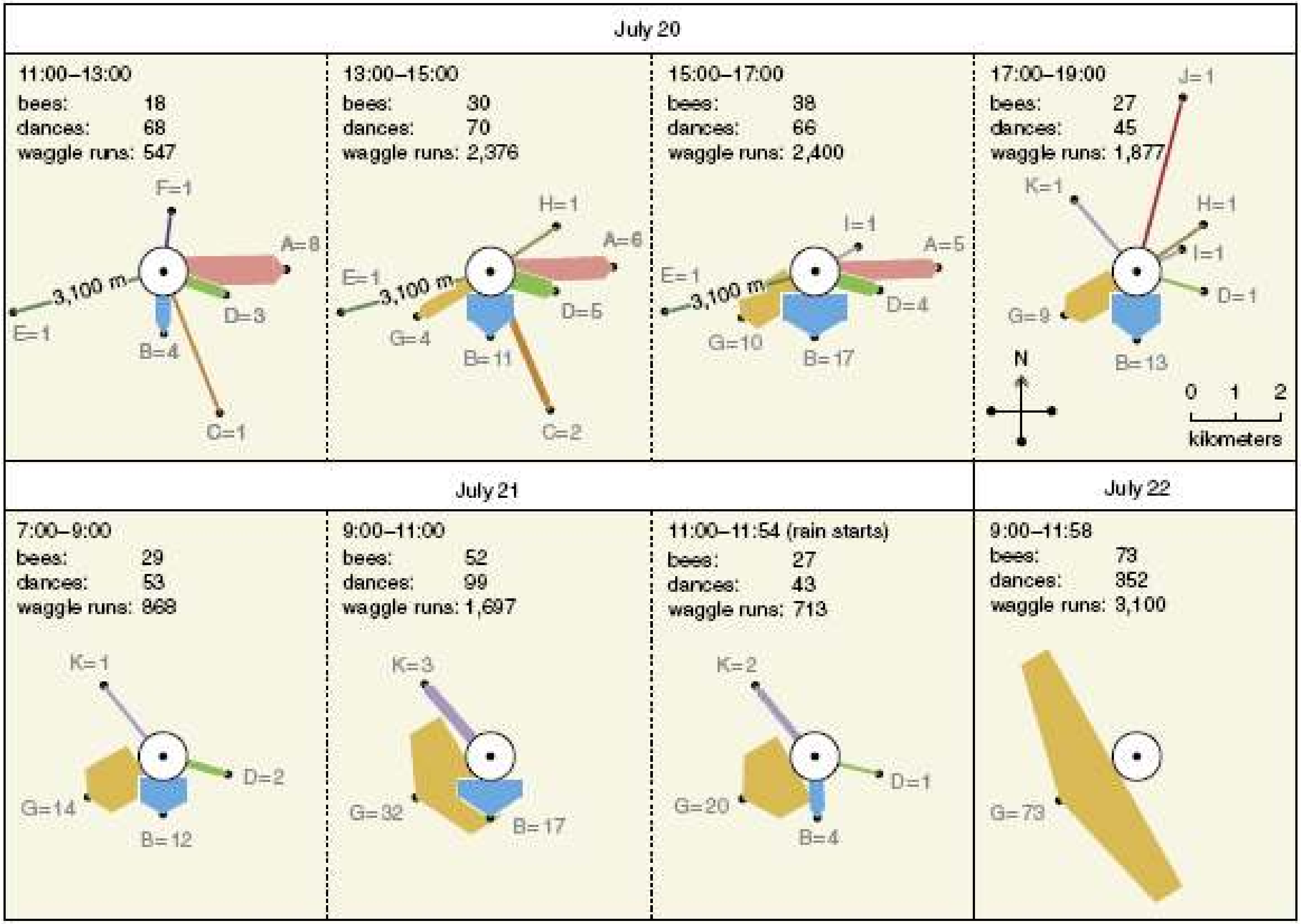


Figure 5. This schematic summarizes a swarm's process of reaching a quorum for a nest site. Each panel summarizes a one- to three-hour interval of activity and lists the total number of bees, dances and waggle runs during this interval. The white circle represents the swarm. Candidate nest sites *(black dots)* are assigned letters in the order in which the bees reported them. Each arrow indicates direction and distance to a site; the thickness of the arrow correlates with how many bees are dancing in support of that site during the interval, as shown by the number next to each site's letter designation. In this case, the swarm considered a total of 11 sites over three days, but none was advertised much more strongly than the others during the first half of the decision-making process. During the second half, however, site G gradually gained support and became the subject of all the dances.

Seeley et al (2006)

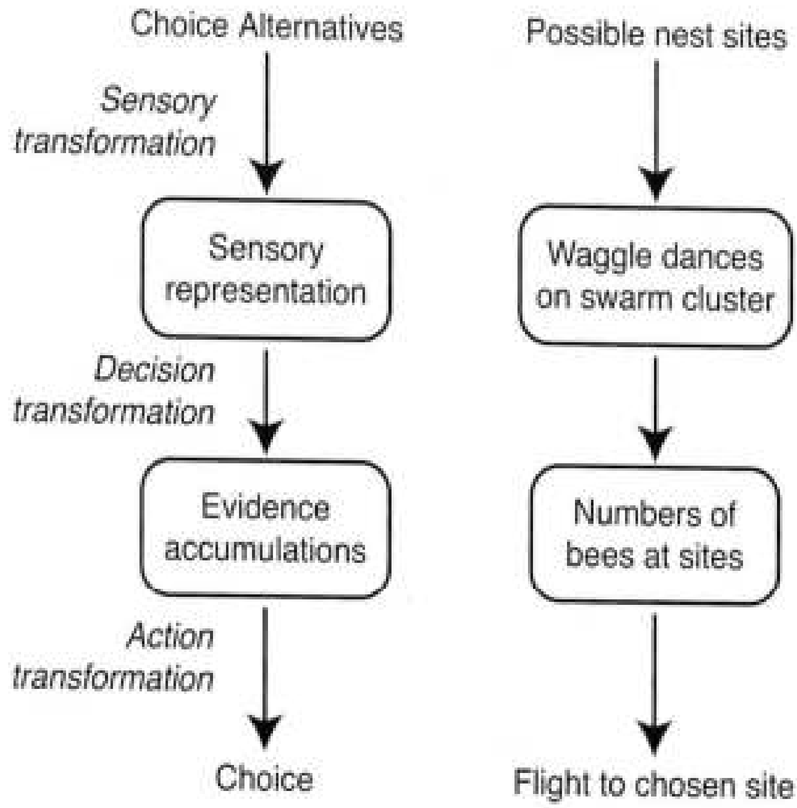
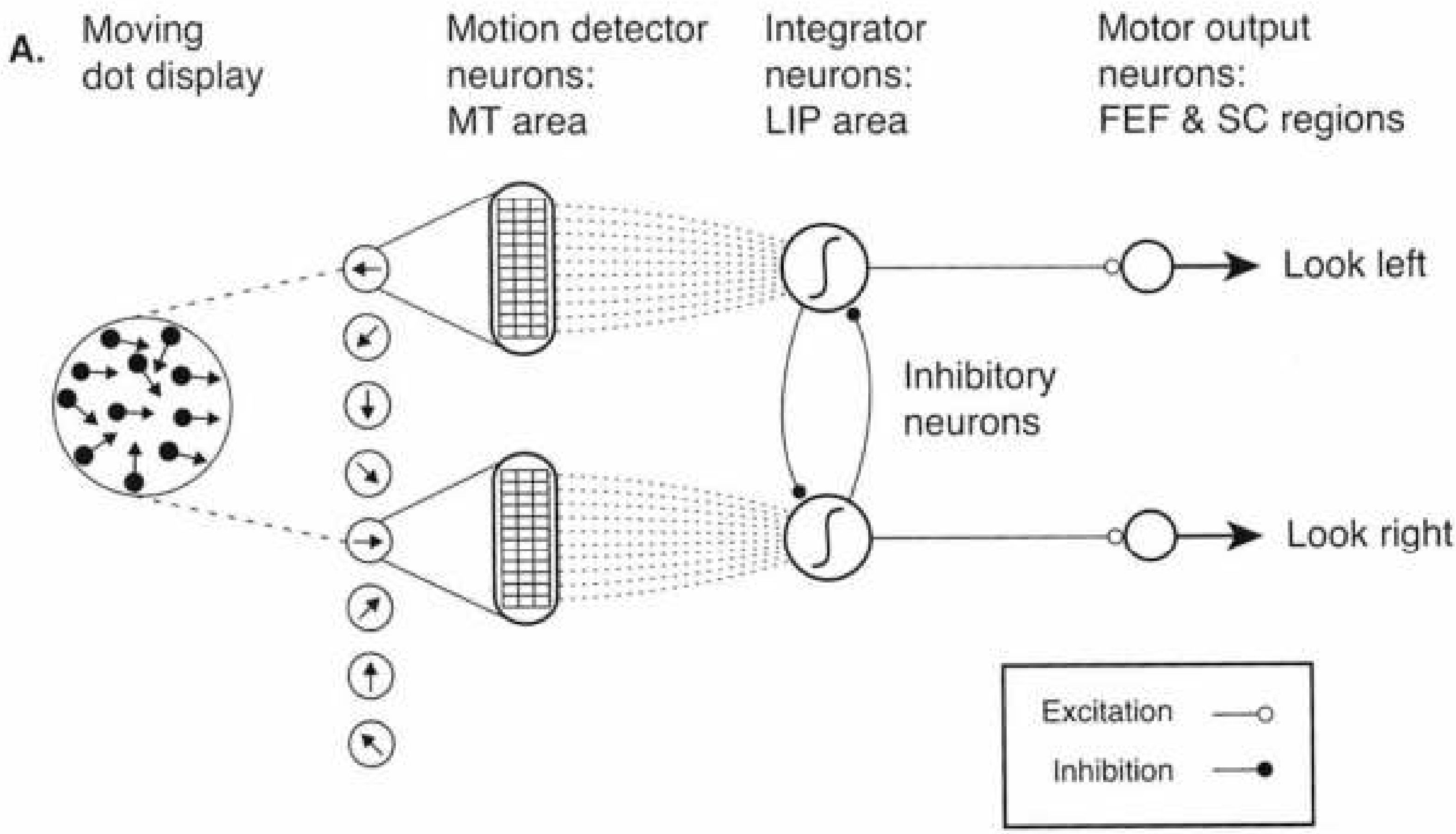


Fig. 9.3 Conceptual framework for decision making that illustrates the processing stages for making a decision (left) and the application of this framework to the mechanisms of nest-site choice by a honeybee swarm (right).

Seeley et al (2006)



A.
Moving dot display
Motion detector neurons: MT area
Integrator neurons: LIP area
Motor output neurons: FEF & SC regions
Look left
Inhibitory neurons
Look right
Excitation
Inhibition

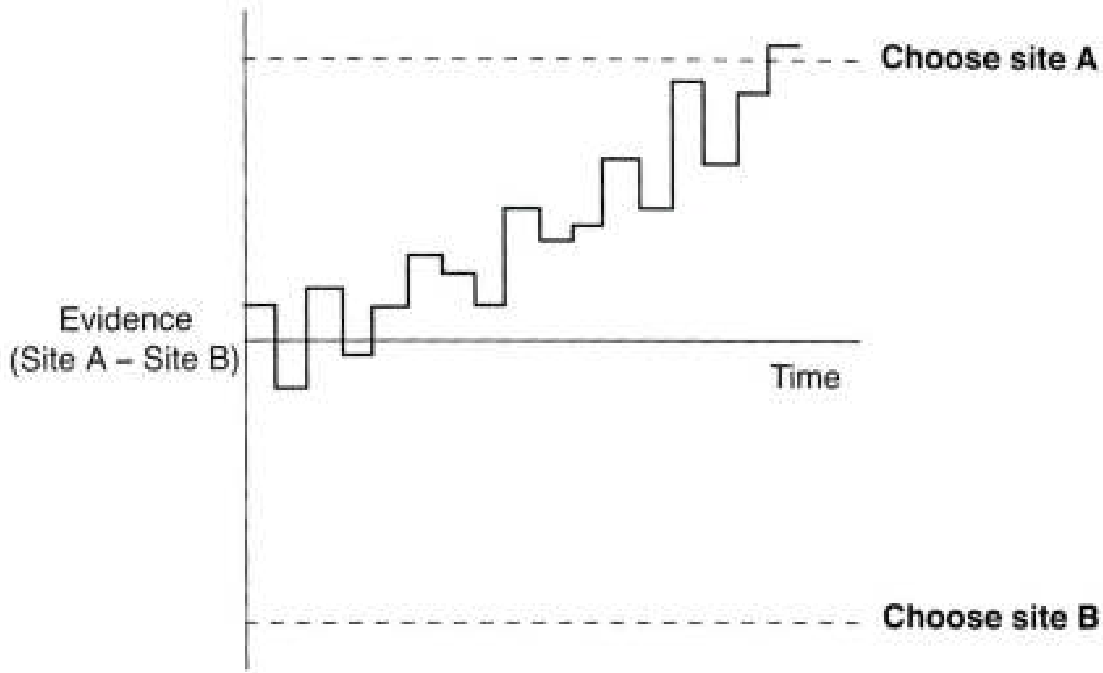
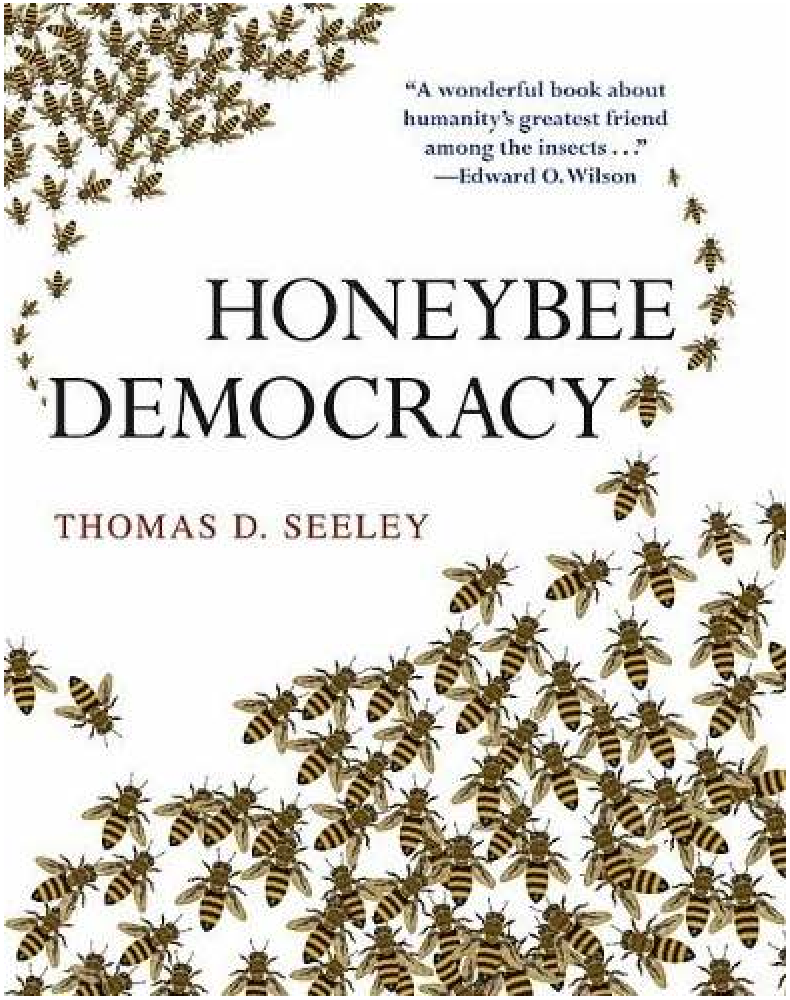


Fig. 9.6 Random walk model in which the evidence about two sites is accumulated as a single total. Evidence for site A increases the total while evidence for site B decreases it. A choice is made when the net gain in evidence for one site exceeds a threshold level.

Additional perspectives



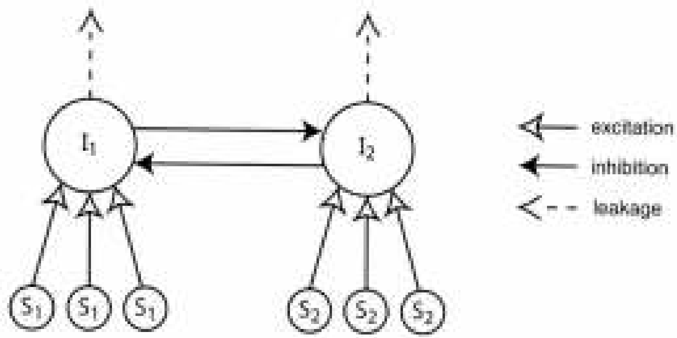
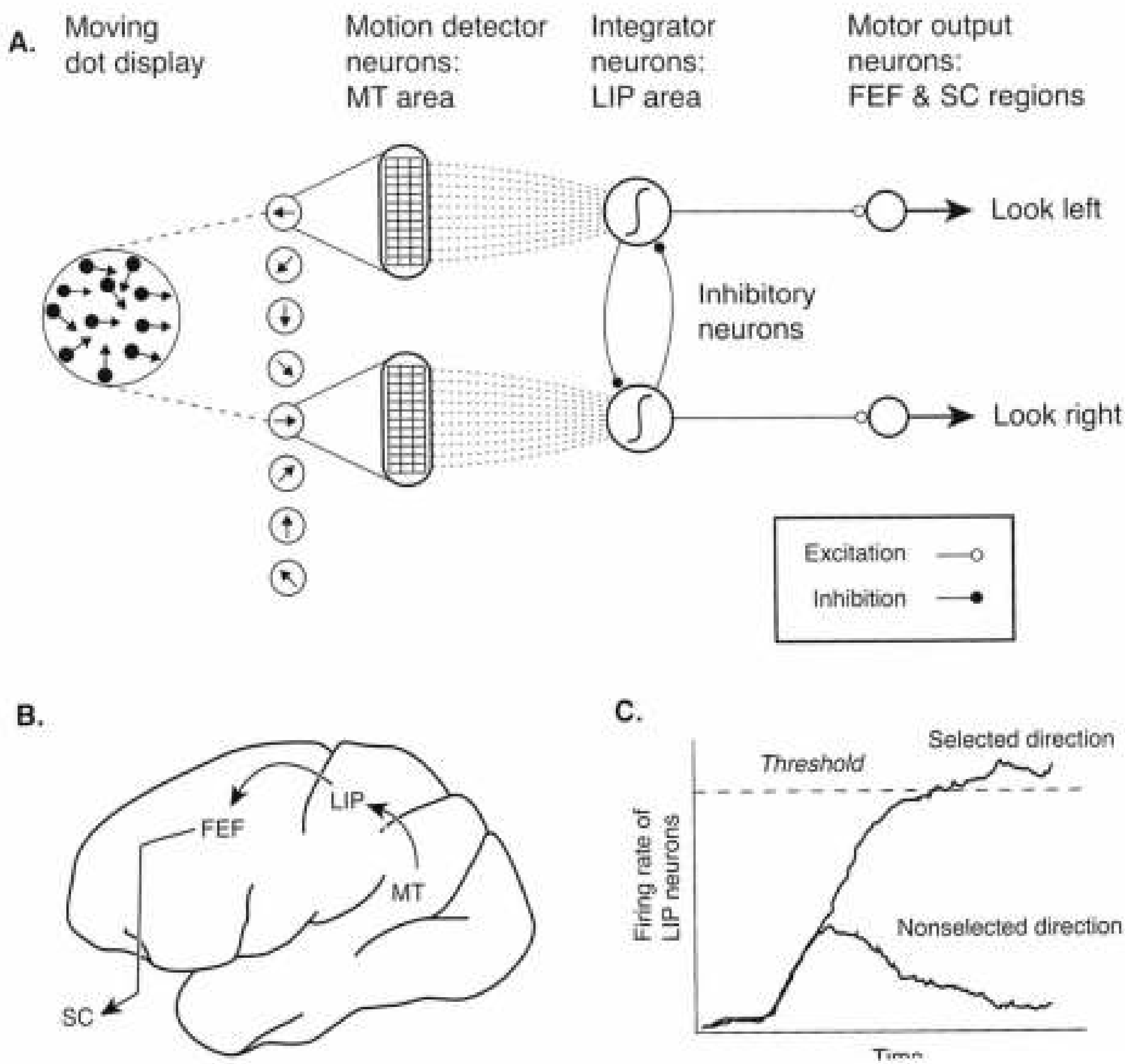


Fig. 9.5 A model of decision making in primate brains and honeybee swarms. In each, populations of neurons or bees represent accumulated evidence for the alternative choices. These populations (I_1 and I_2) integrate noisy inputs from sensory units (S_1 and S_2), and they slowly leak their accumulated evidence. Each population also inhibits the other in proportion to its level of activity (neurons) or its size (bees).



Seeley et al (2006)

Take-home message

- ✓ The ‘diffusion’ model: choice should be made as soon as the difference between the evidence supporting the winning alternative and the evidence supporting the losing alternative exceeds a threshold
- ✓ **Nervous system can actually perform ‘diffusion’ model-like calculations.**

Thank you for your attention!