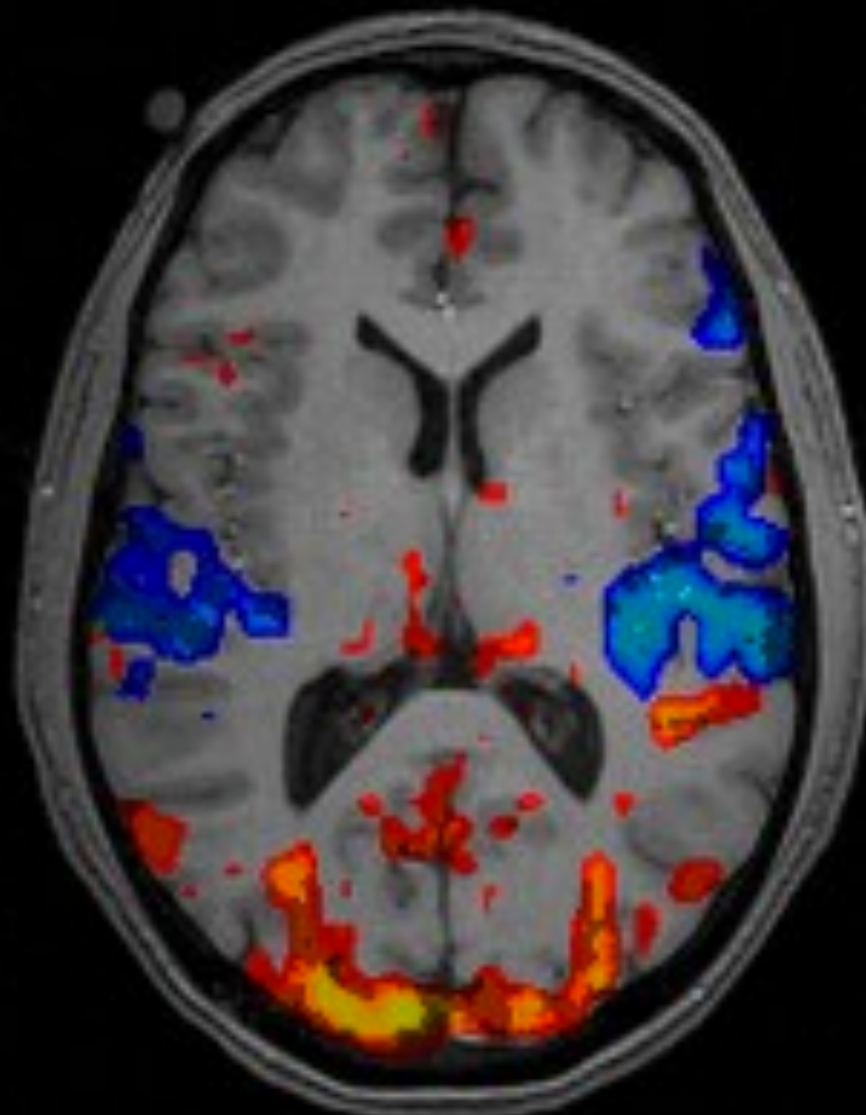
ASHI636: Advanced Neuroscience

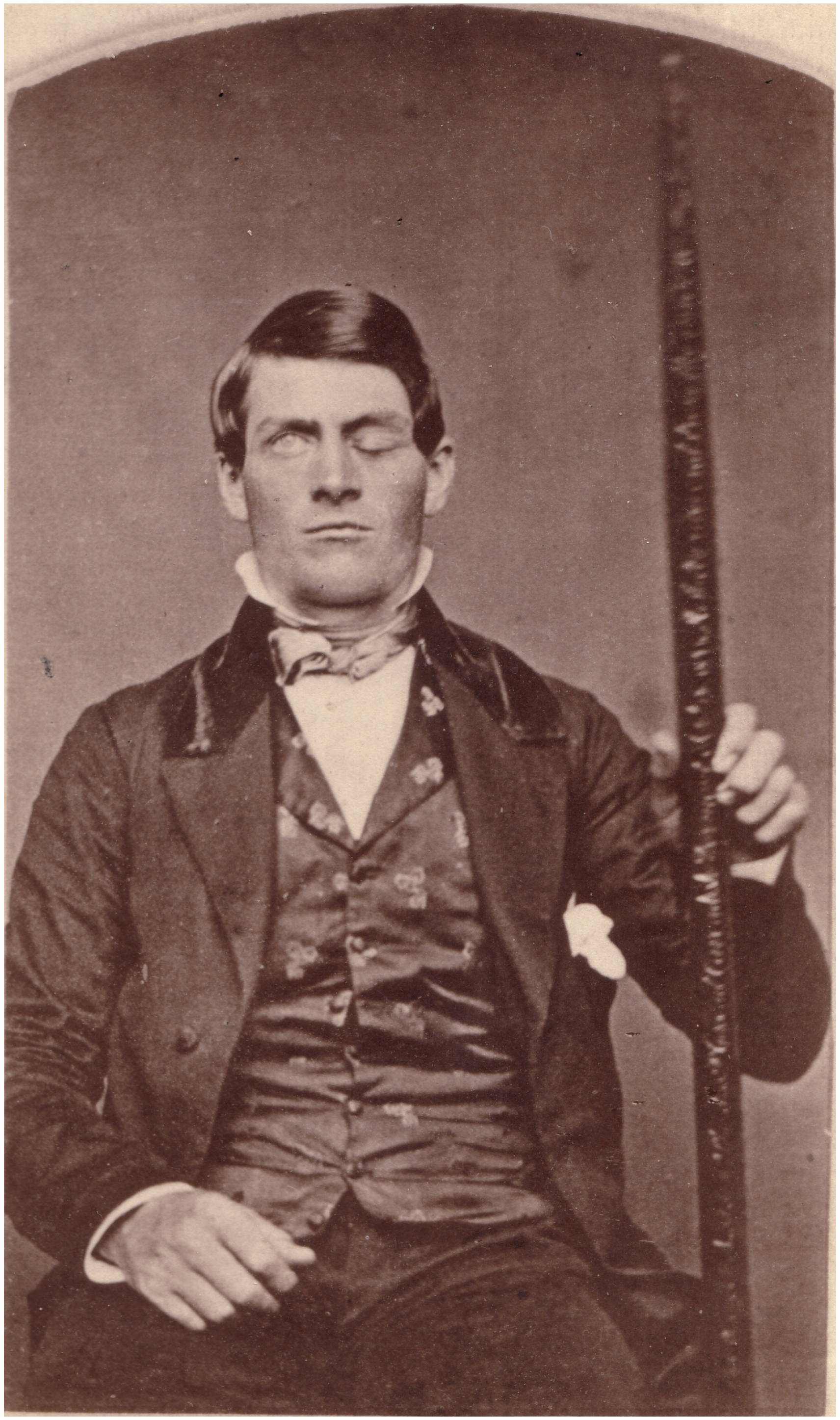
Dr. Olav E. Krigolson

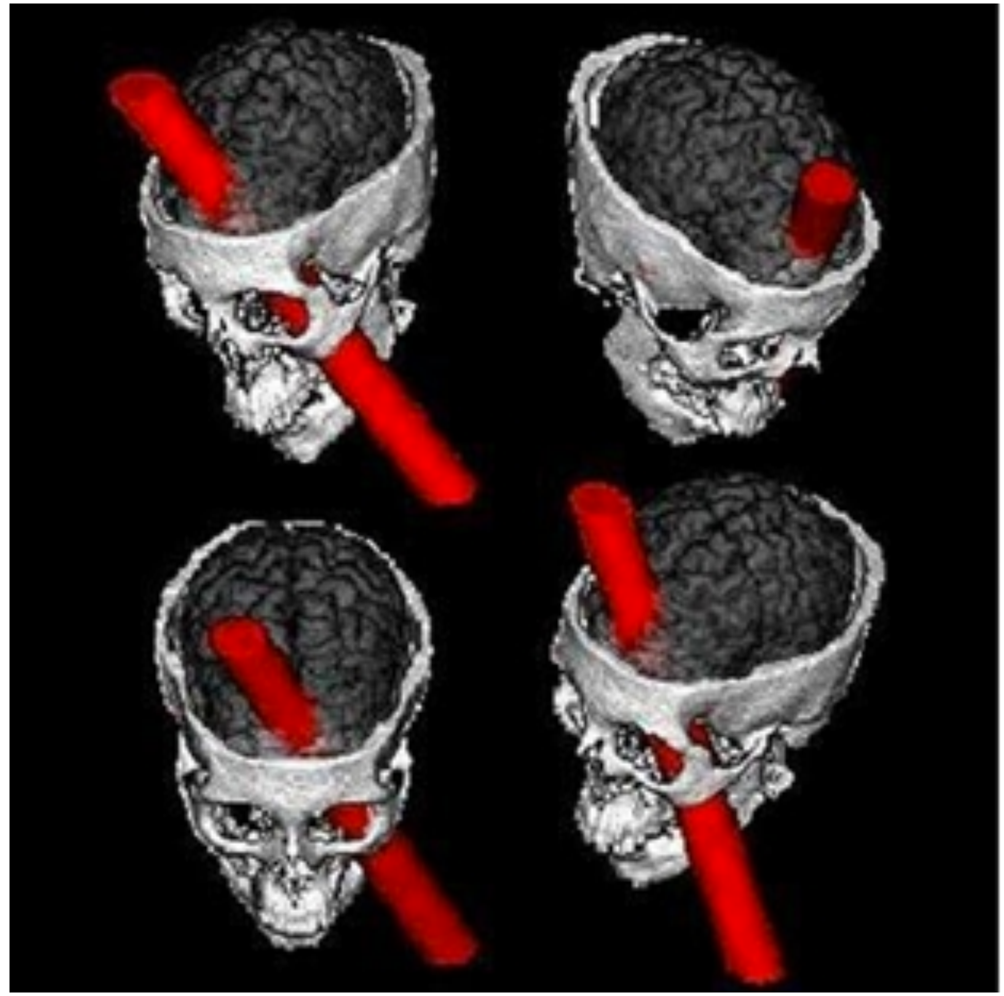
Lecture 3: Executive Control



What is executive control?

Phineas Gage





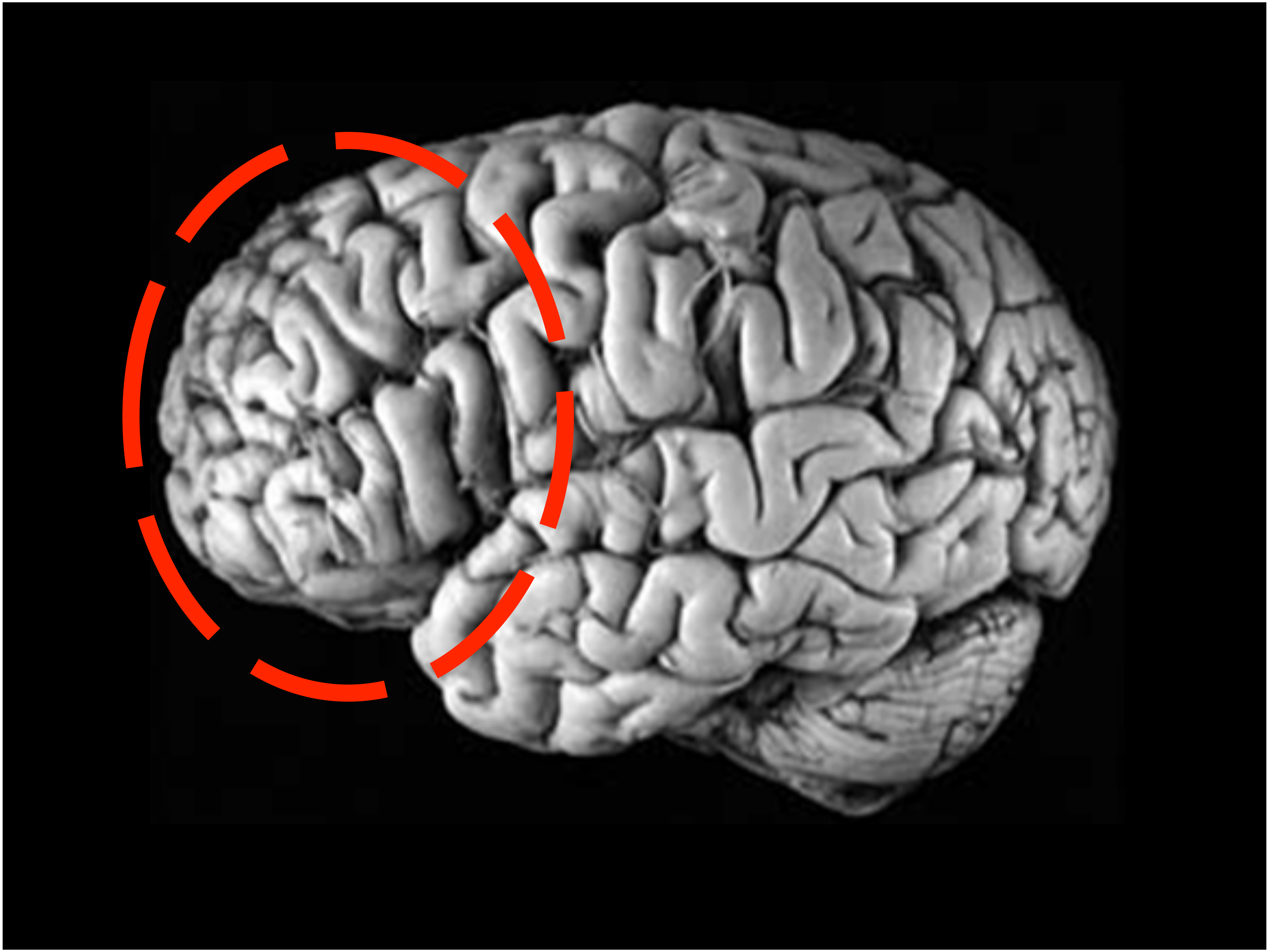
In 1848, Gage, 25, was the foreman of a crew cutting a railroad bed in Cavendish, Vermont. On September 13, as he was using a tamping iron to pack explosive powder into a hole, the powder detonated. The tamping iron - 43 inches long, 1.25 inches in diameter and weighing 13.25 pounds - shot skyward, penetrated Gage’s left cheek, ripped into his brain and exited through his skull, landing several dozen feet away. Though blinded in his left eye, he did not lose consciousness and remained savvy enough to tell a doctor that day, “Here is business enough for you.”

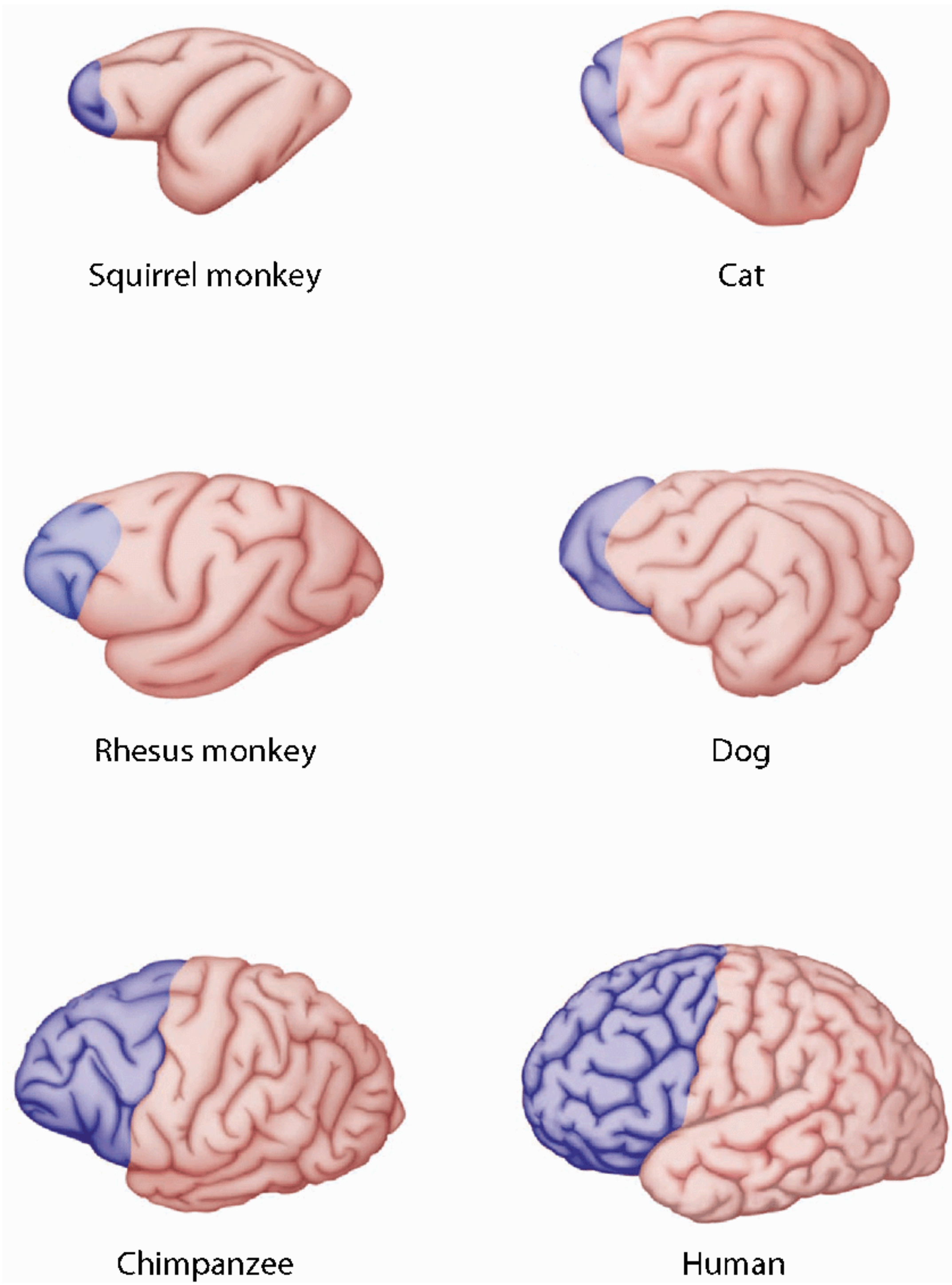
Gage’s initial survival would have ensured him a measure of celebrity, but his name was etched into history by observations made by John Martyn Harlow, the doctor who treated him for a few months afterward. Gage’s friends found him “no longer Gage,” Harlow wrote. The balance between his “intellectual faculties and animal propensities” seemed gone. He could not stick to plans, uttered “the grossest profanity” and showed “little deference for his fellows.” The railroad-construction company that employed him, which had thought him a model foreman, refused to take him back. So Gage went to work at a stable in New Hampshire, drove coaches in Chile and eventually joined relatives in San Francisco, where he died in May 1860, at age 36, after a series of seizures.

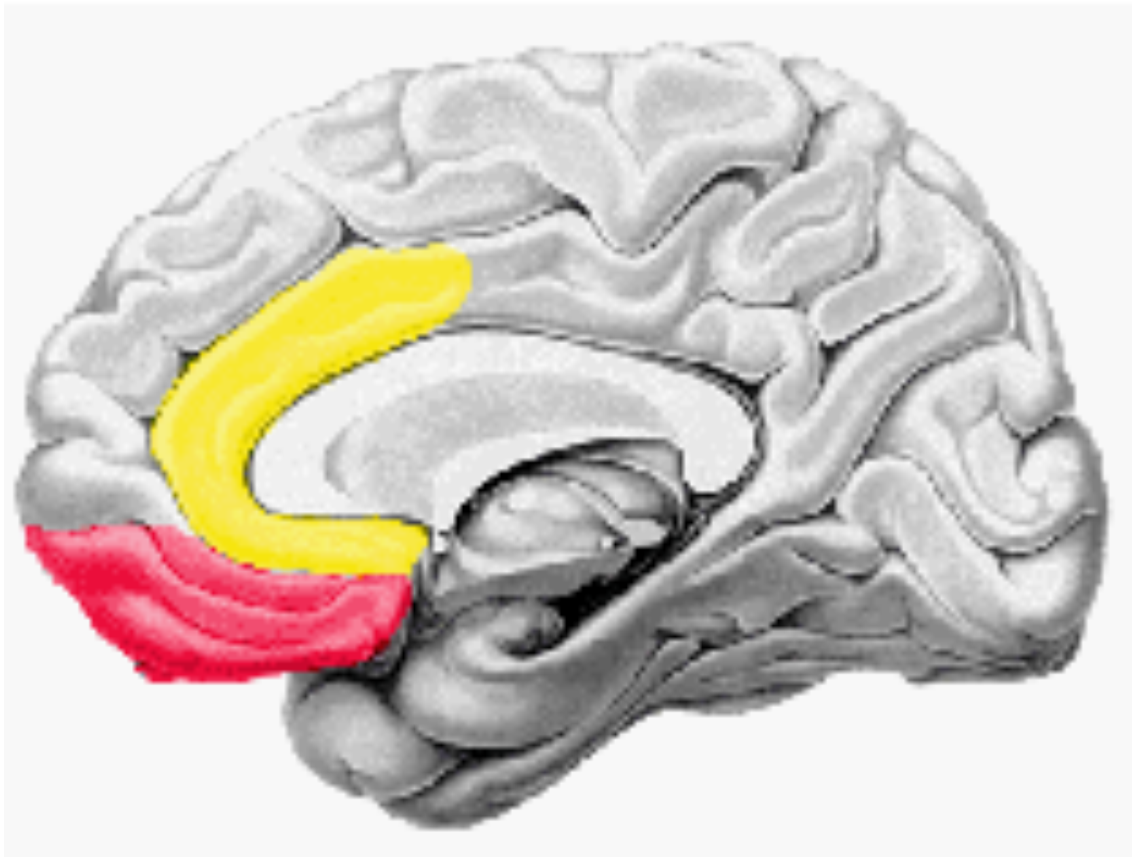
Dr. P. was a successful middle-aged surgeon who used the financial rewards of his practice to pursue his passion for traveling and playing sports. Tragically, while he was undergoing minor facial surgery, complications caused his brain to be deprived of oxygen for a short period. The ensuing brain damage had profound negative consequences on his mental functioning, compromising his ability to plan, to adapt to change, and to act independently.

After the surgery, standard IQ tests revealed Dr. P.'s intelligence to be, for the most part, in the superior range. Yet, he could not handle many simple day-to-day activities and was unable to appreciate the nature of his deficits. His dysfunction was so severe that not only was returning to work as a surgeon impossible for him, but in addition his brother had to be appointed his legal guardian. As a surgeon, Dr. P. had skillfully juggled many competing demands and had flexibly adjusted to changing situations. Now, however, he was unable to carry out all but the most basic routines and then only in a rigid, routinized manner. Furthermore, he had lost his ability to initiate actions and to plan for the future. For example, his sister-in-law had to tell him to change his clothes, and only after years of explicit rule-setting did he learn to do so on his own. He managed to work as a delivery truck driver for his brother's business, but only because his brother could structure the deliveries so that they involved minimal planning. Dr. P. could not be provided with an itinerary for the deliveries of the day because he was incapable of advance planning. Rather, his brother would give him information about one delivery at a time. After each delivery, Dr. P. would call in for directions to the next stop.

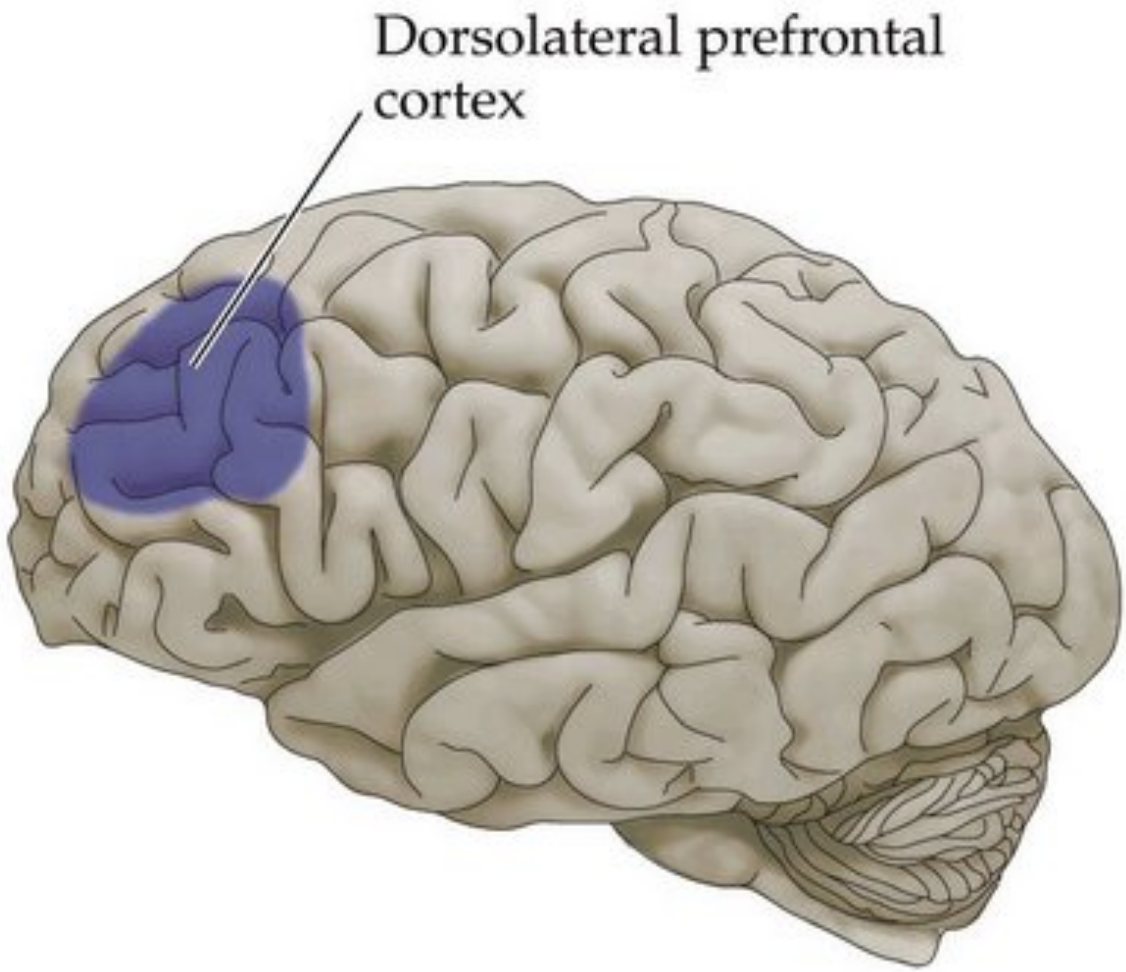
Dr. P. also was totally unaware of his situation. He seemed unconcerned and uninterested in how he was provided with the basic necessities of life, such as clothes, food, and lodging, and was totally complacent about being a ward of his brother and sister-in-law. Formerly an outgoing man, he now spoke in a monotone and expressed little emotion. He did not initiate any activities or ask questions about his existence, being content to spend his free time watching television. ■

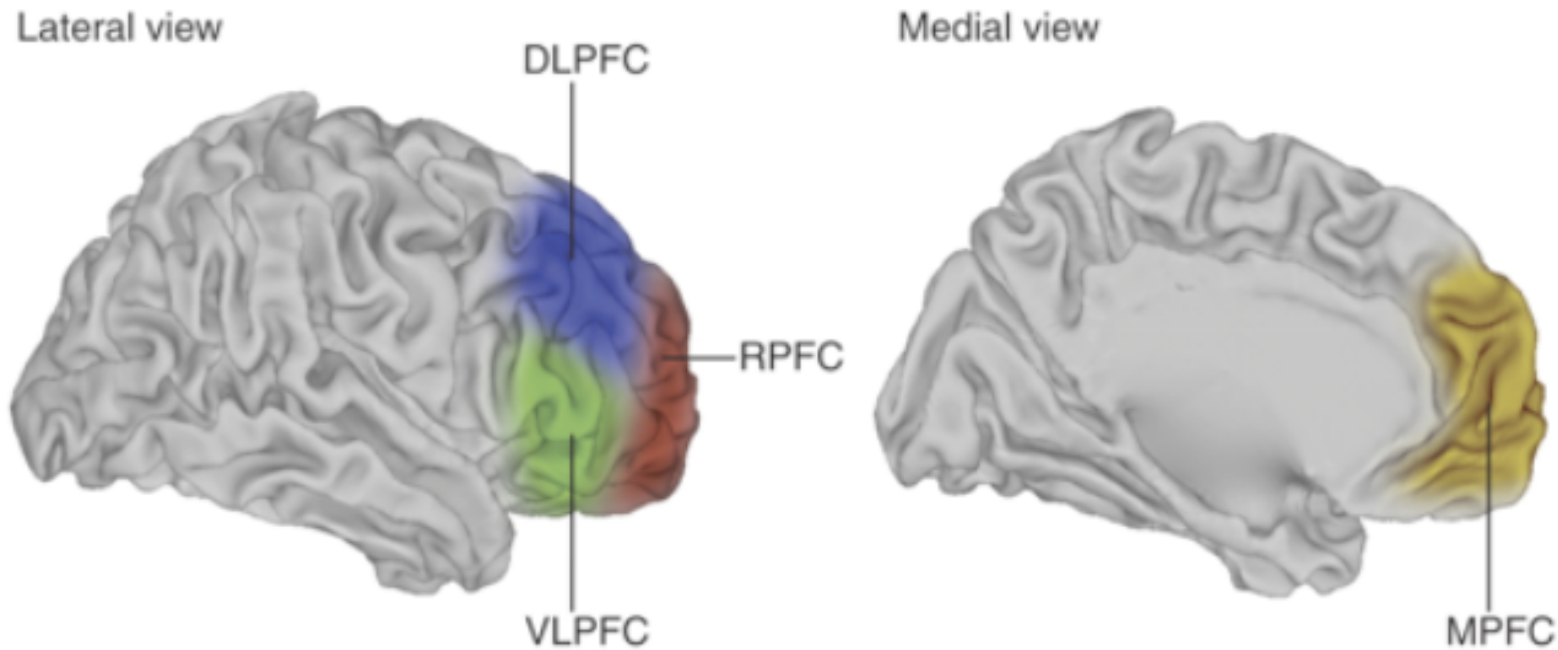


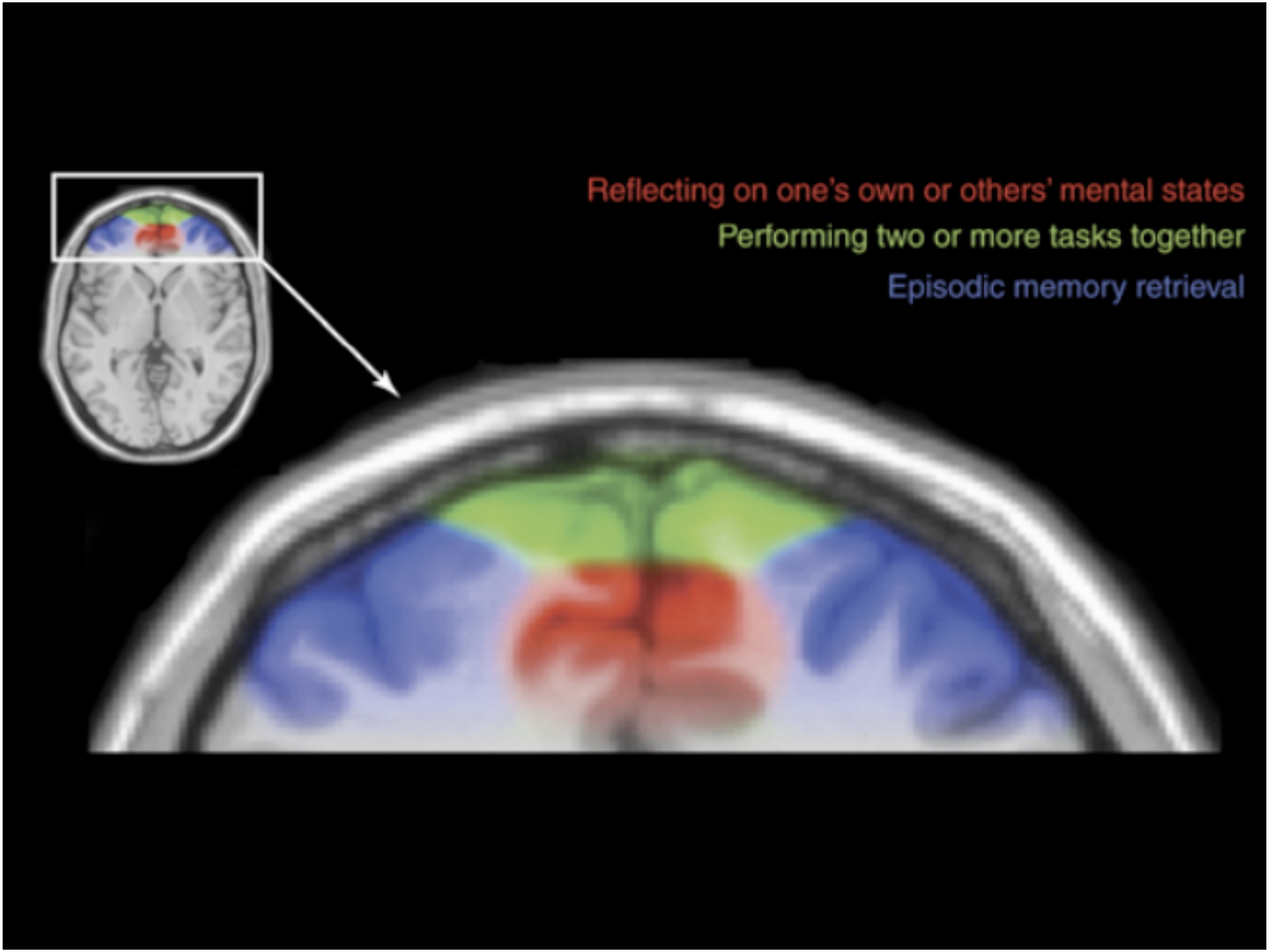

Squirrel monkey
Cat
Rhesus monkey
Dog
Chimpanzee
Human



Orbitofrontal Cortex


Dorsolateral prefrontal
cortex

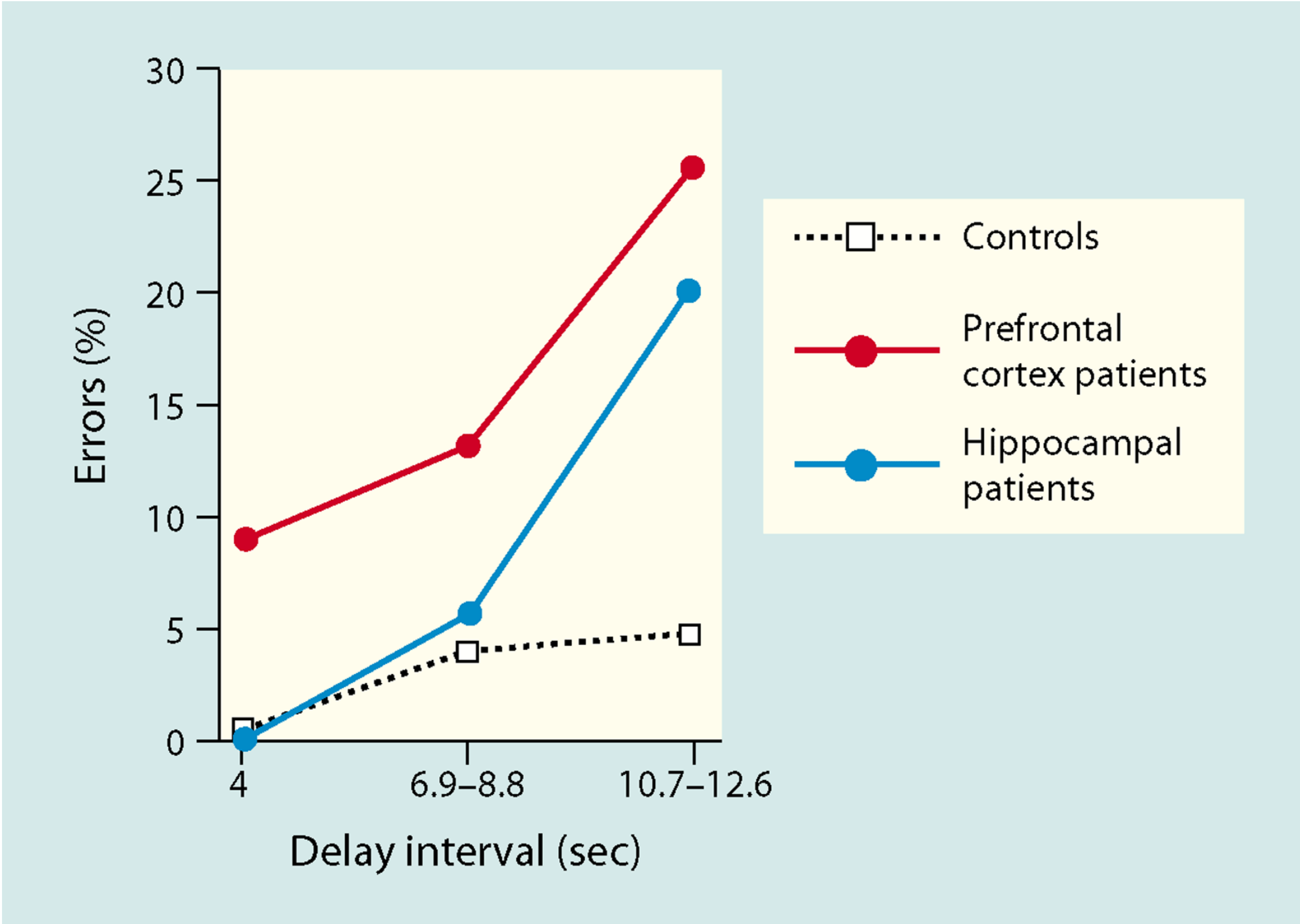

Lateral view
DLPFC
RPFC
VLPFC
Medial view
MPFC


Reflecting on one's own or others' mental states
Performing two or more tasks together
Episodic memory retrieval

Executive Control and Working Memory

Sunglasses
Chair
Dress
Earrings
Boots
Bed
Counter
Shower
Floor
Shoes
Desk

What was the list of words?



Subjects performed a **delayed auditory matching-to-sample** task. Unrelated distractors tones were presented during the delay period. Patients with prefrontal lesions made more errors for all delay conditions and the deficits became greater as the number of distractors increased. Patients with hippocampal lesions were impaired only at the longest deay (Chao and Knight, 1995).

What is the average of the following numbers?

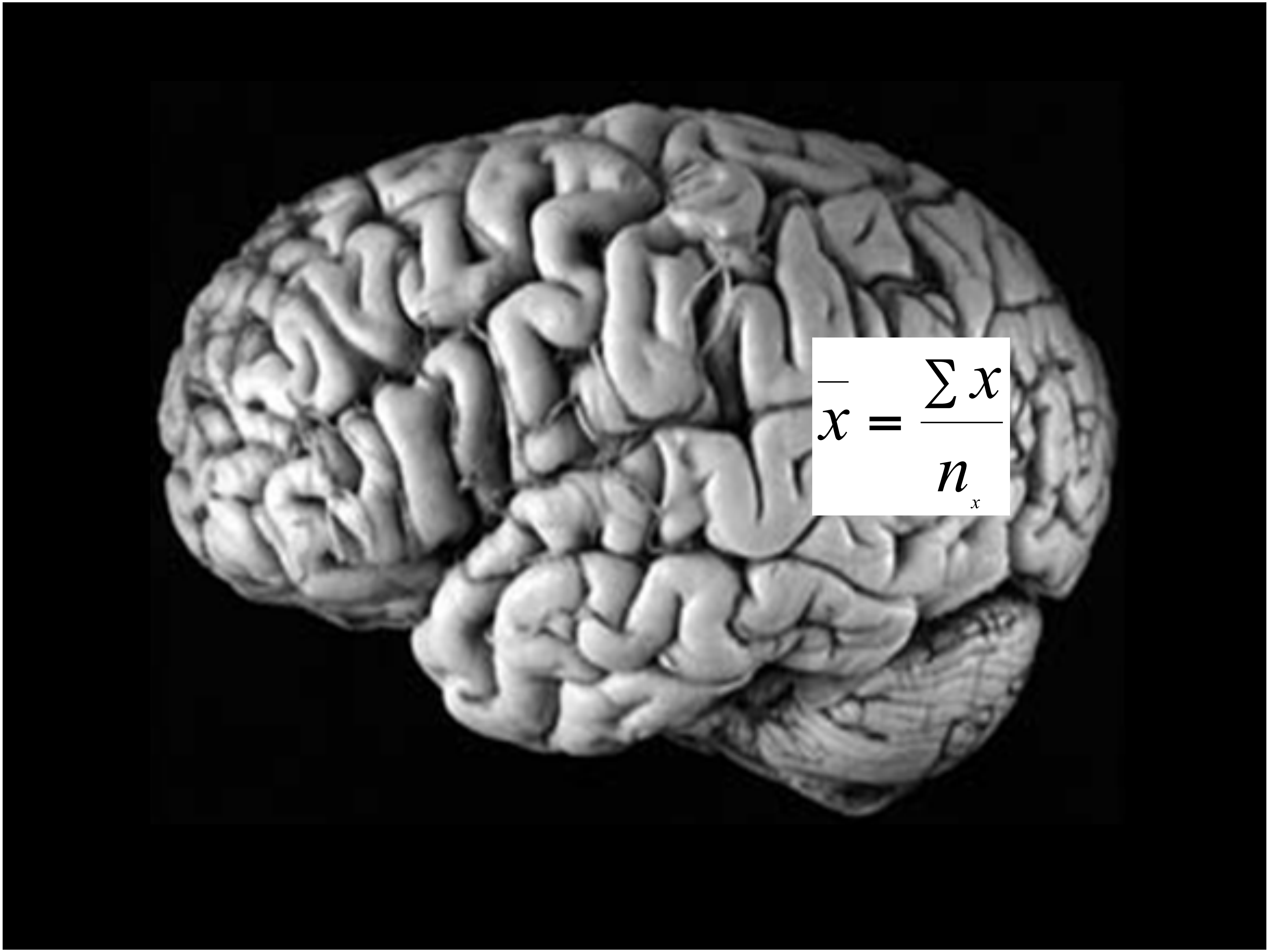
1

3

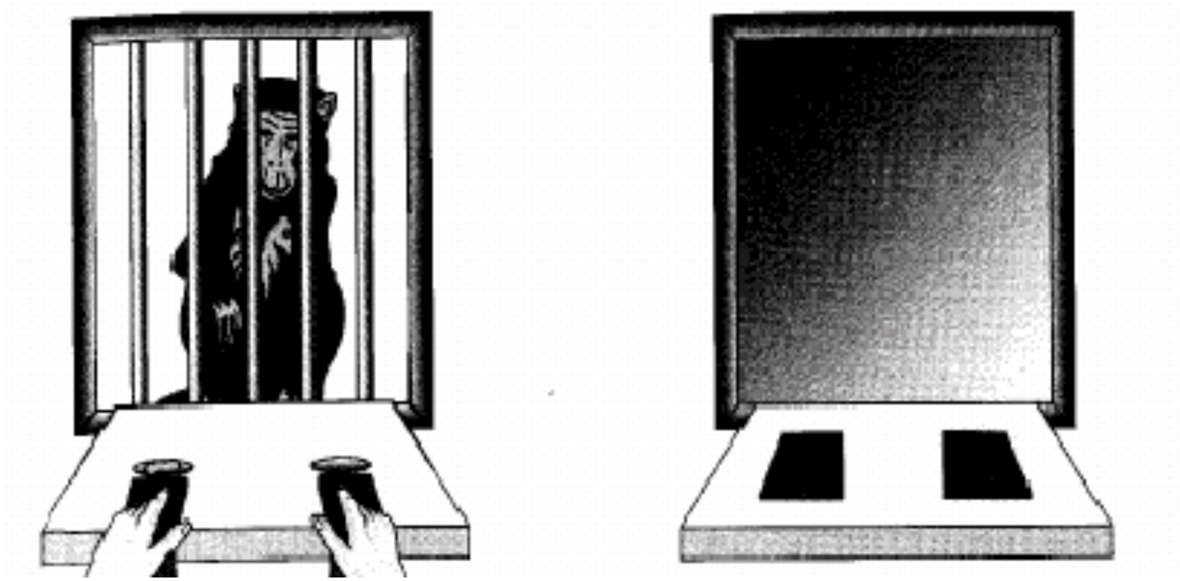
6

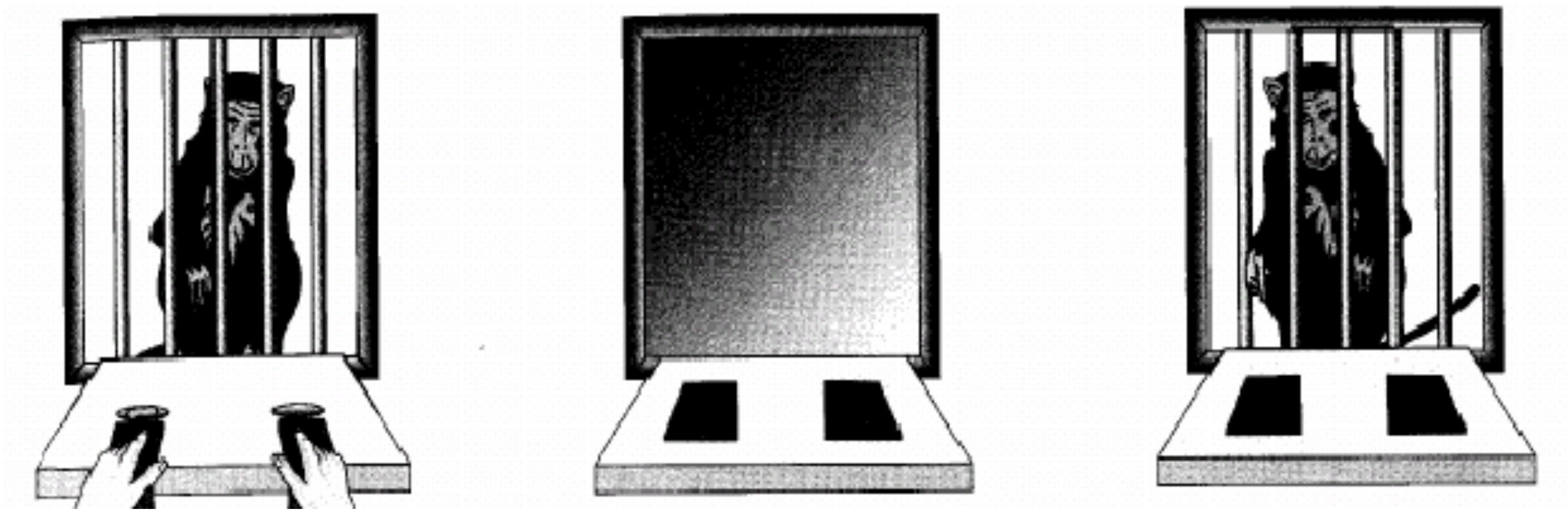
9

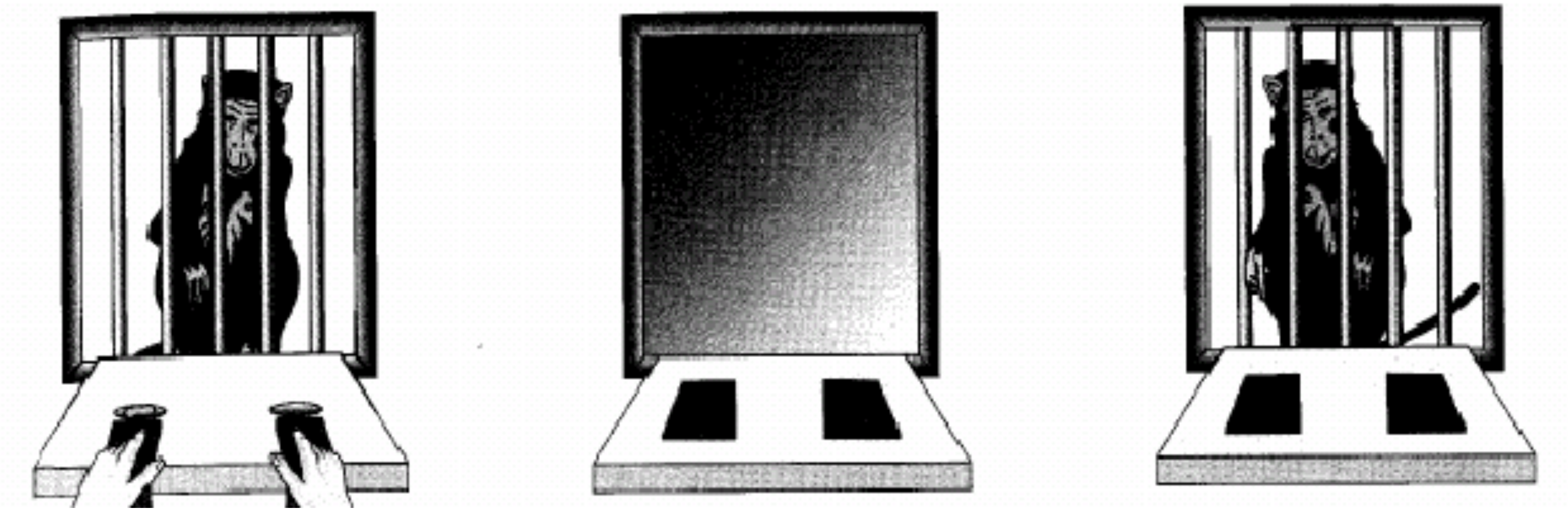
11



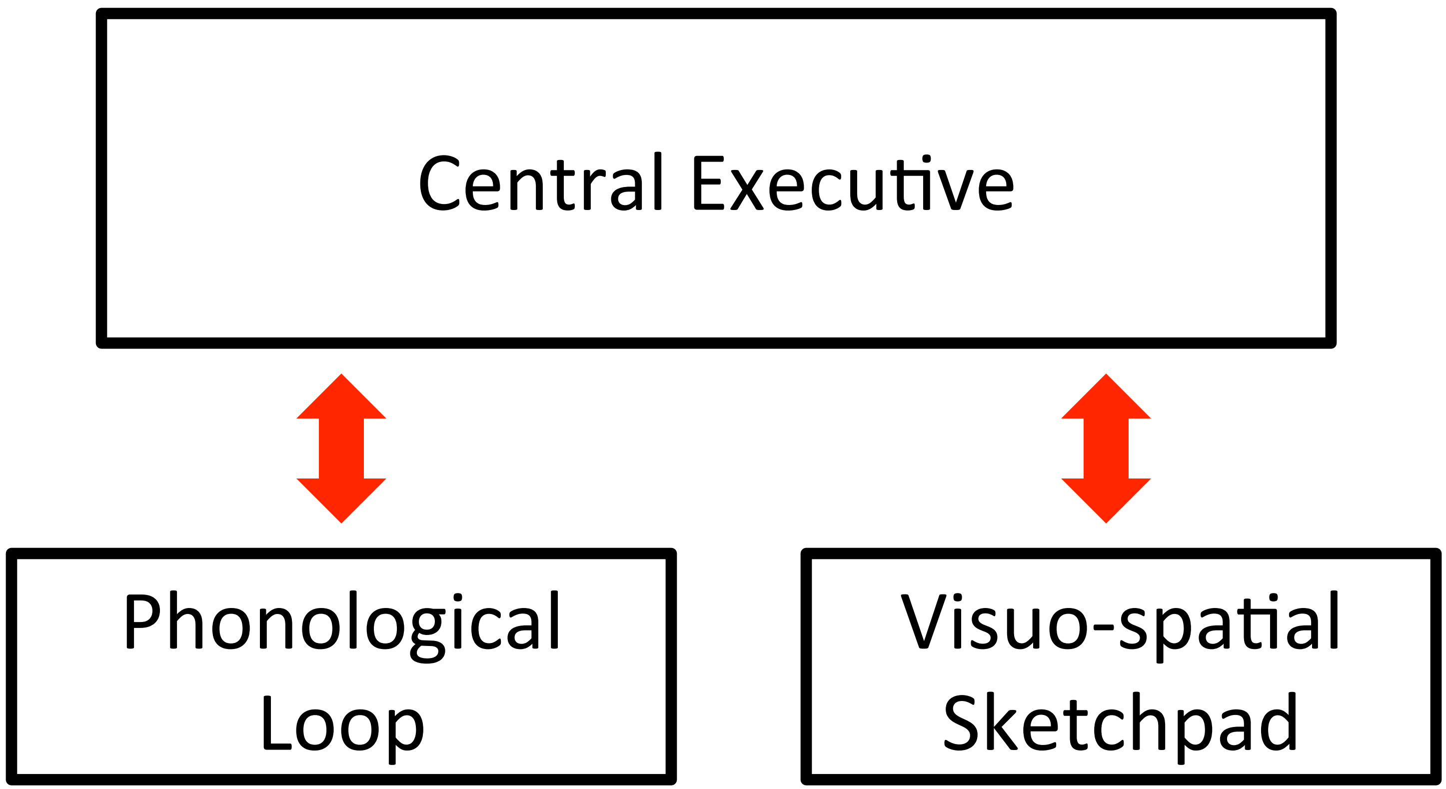
$$\bar{x} = \frac{\sum x}{n_x}$$







Monkeys with damage to Prefrontal Cortex cannot do this task



Baddeley & Hitch, 1974

Central Executive

add / delete items from working memory
selecting from items
recall from long term memory
transfer to long term memory

Baddeley & Hitch, 1974

Updating Working Memory

The “n” back task

Target = 4

3

5

1

9

4

1

3

2

8

5

0

6

7

9

2

4

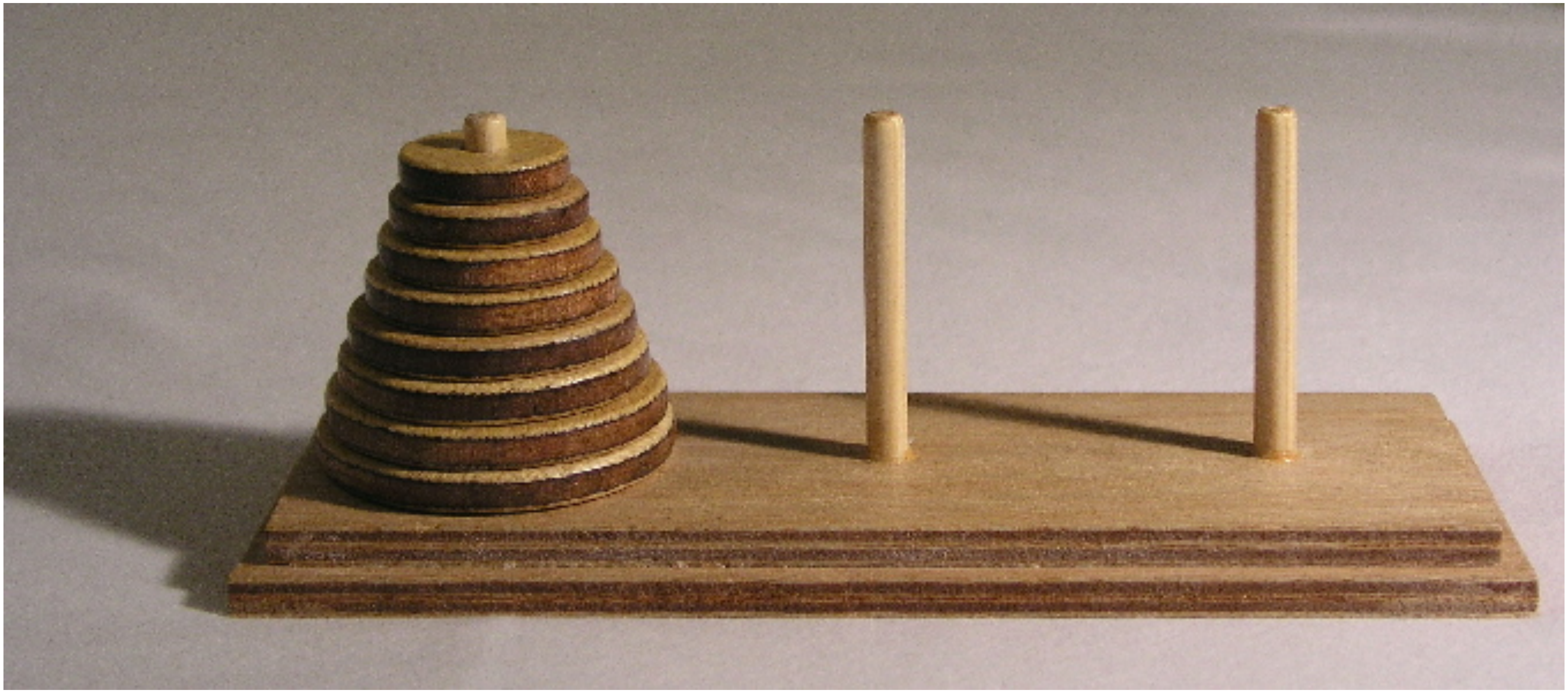
9

Central Executive

control of working memory
setting goals and planning
task switching
stimulus response selection (inhibition)

Setting Goals and Planning

The Towers of Hanoi



http://www.dynamicdrive.com/dynamicindex12/towerhanoi.htm

Goal Setting and Planning is a form of Decision Making

Thus, Markov Decision Making (MDM) rules apply:

1. Always choose the highest value option (Exploitation)
2. Sometimes choose a lower value option (Exploration)

A RL model can solve the Towers of Hanoi Puzzle.

Tower of London Task

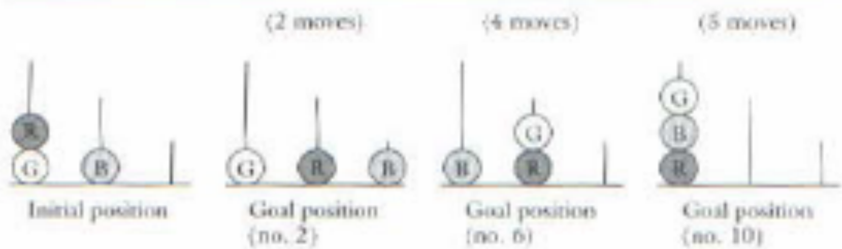


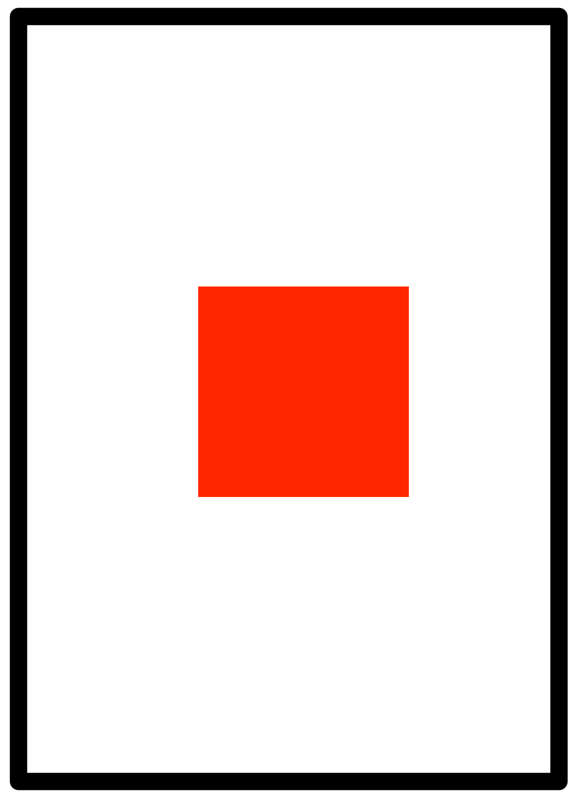
FIGURE 11.7 Example of three problems in Tower of London task. The same initial position is used in each problem. The balls must be moved to the goal position one at a time in as few moves as possible. The number of moves required to reach each goal is noted. R, red; G, green; B, blue.

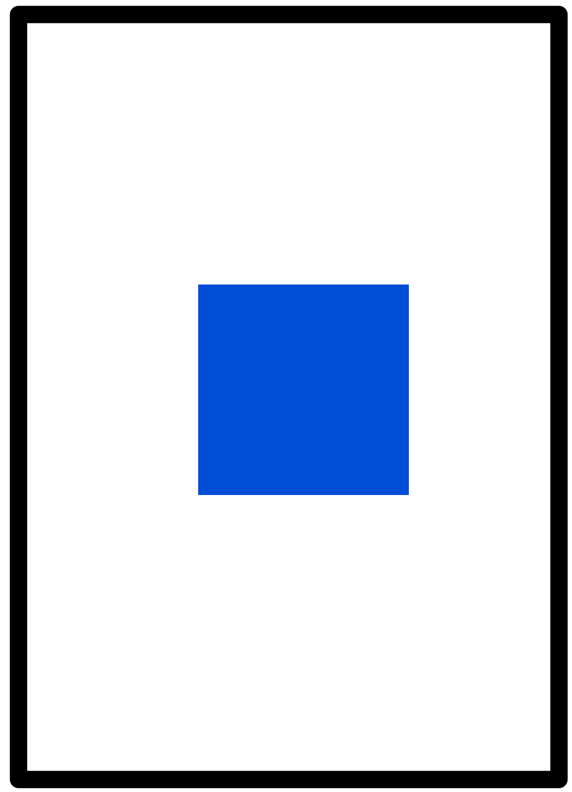
- **Tower of London** task requires planning to reach a goal
- People with dorsolateral prefrontal cortex damage do poorly at the task, because they make aimless moves that are not directed toward the goal
- Functional neuroimaging studies show that DLPFC is activated in this task, and that this area is most activated in those individuals who solve the task in the fewest number of moves

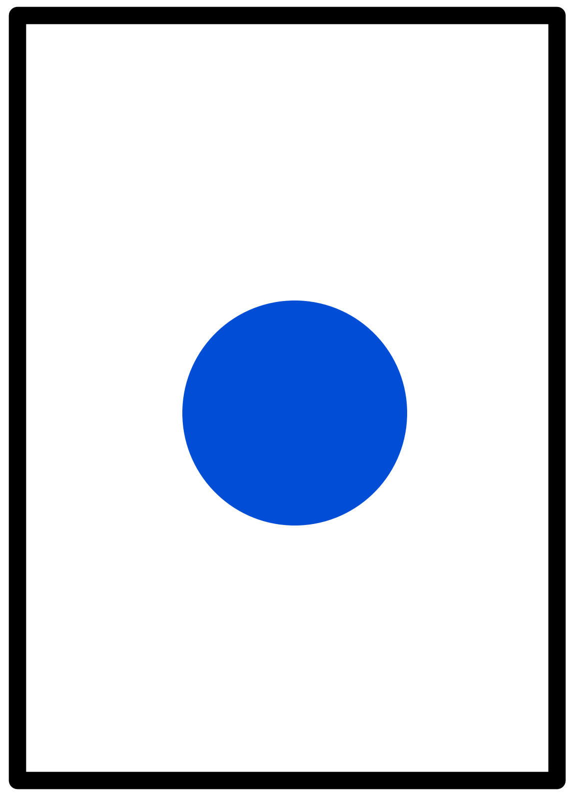
Task Switching

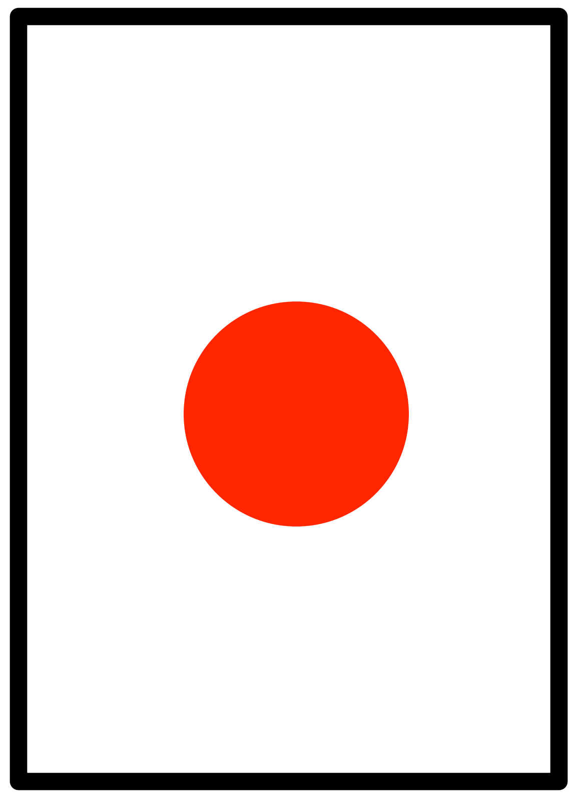
The Wisconsin Card Sort Task

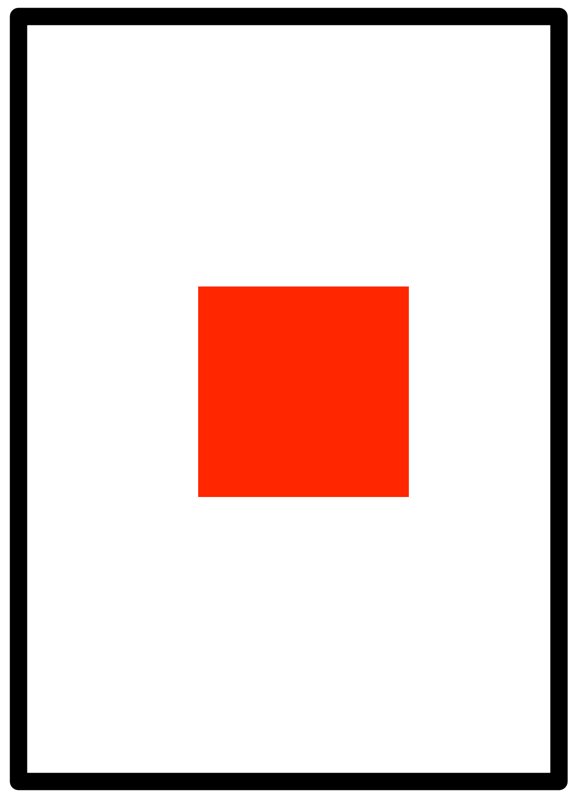
Rule: Shape

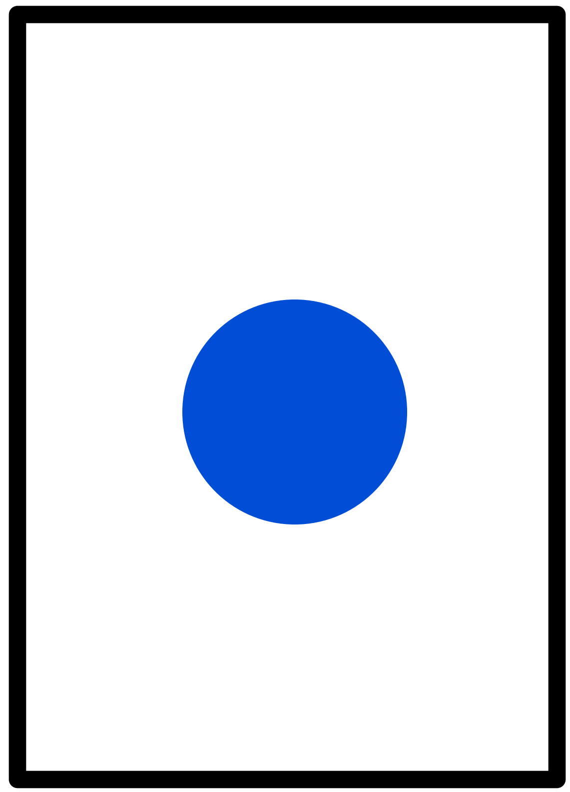


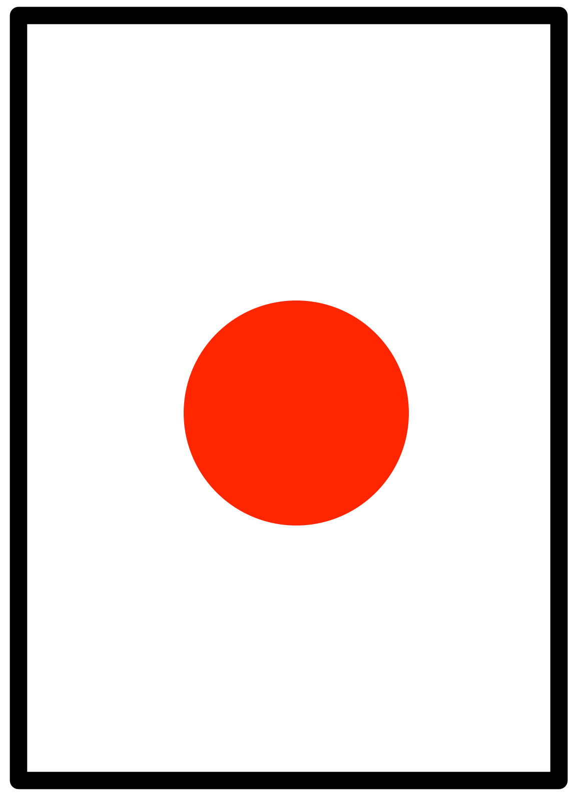




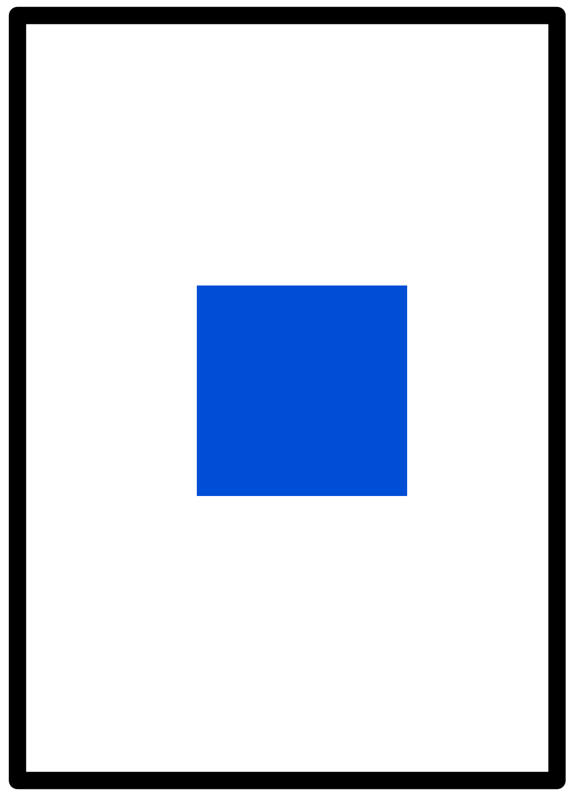


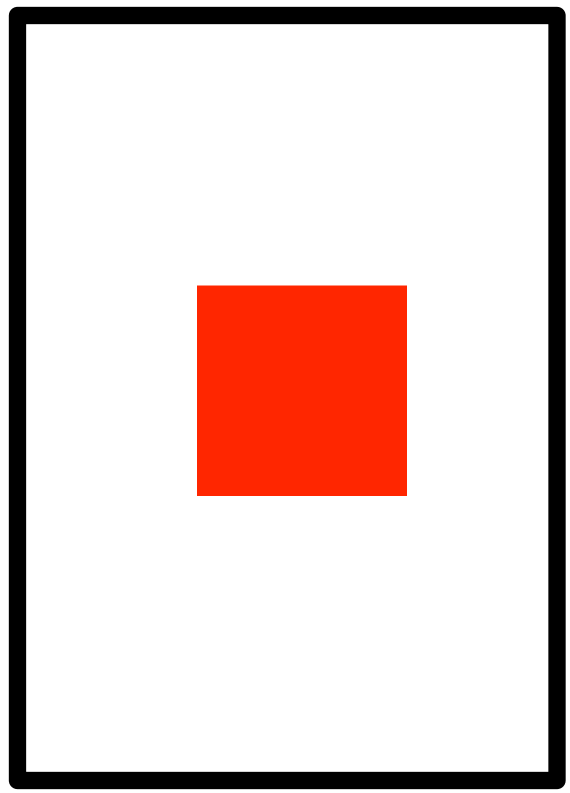


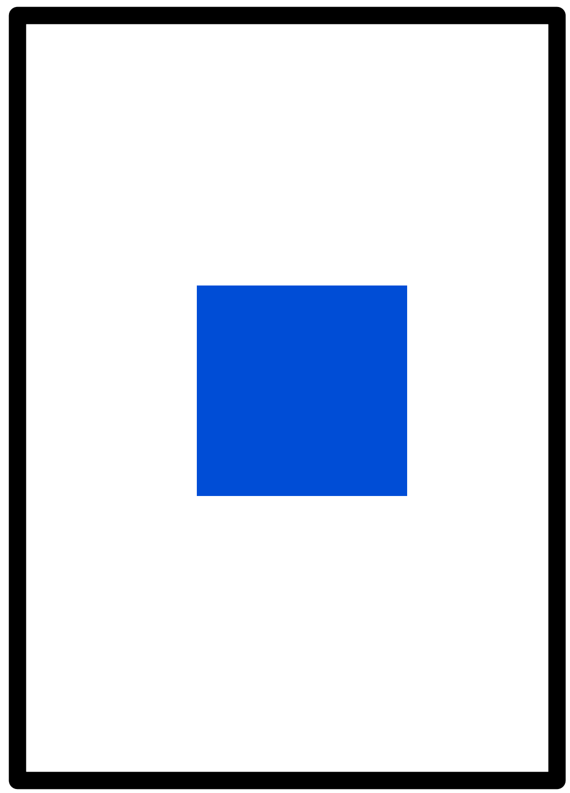


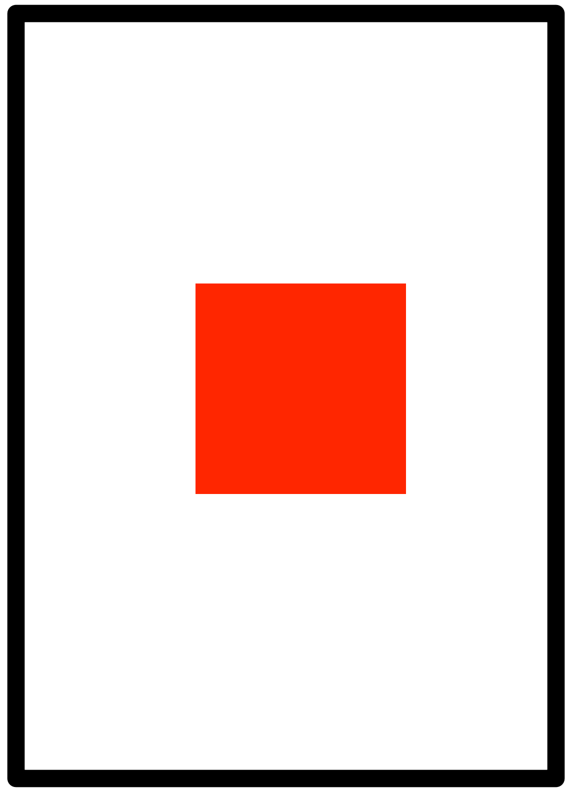


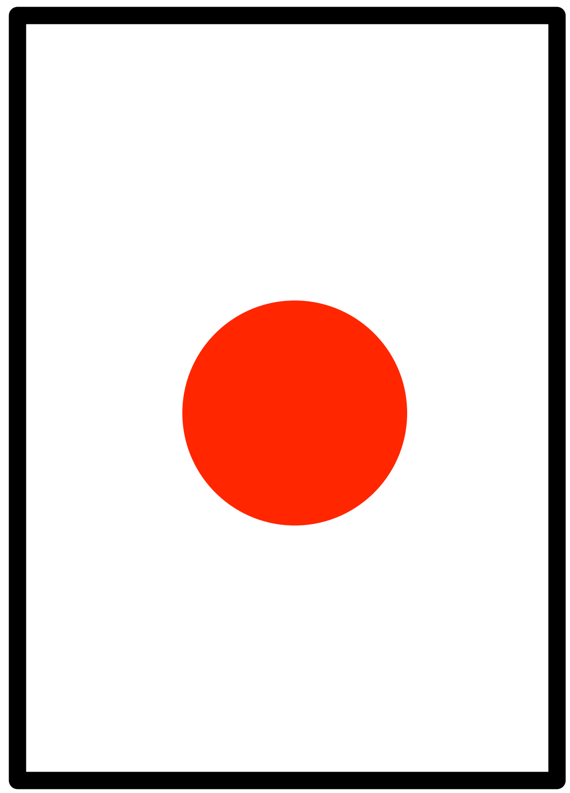
Rule: Colour

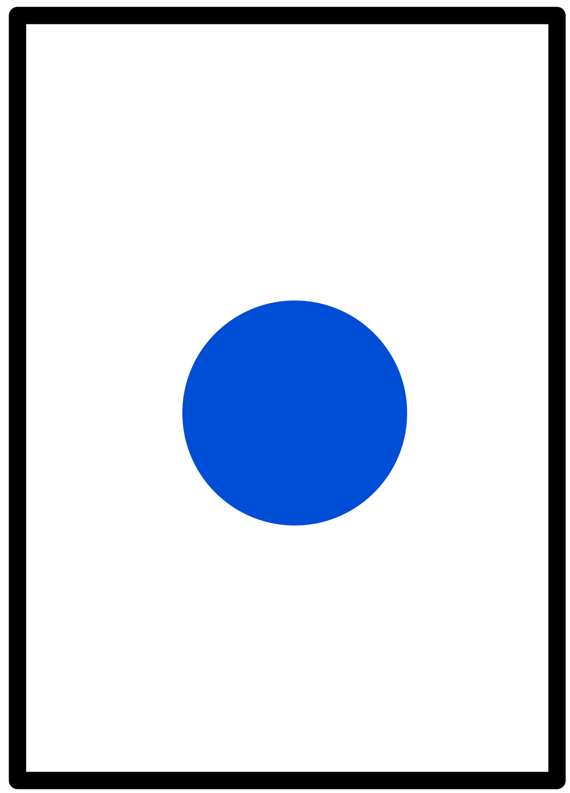


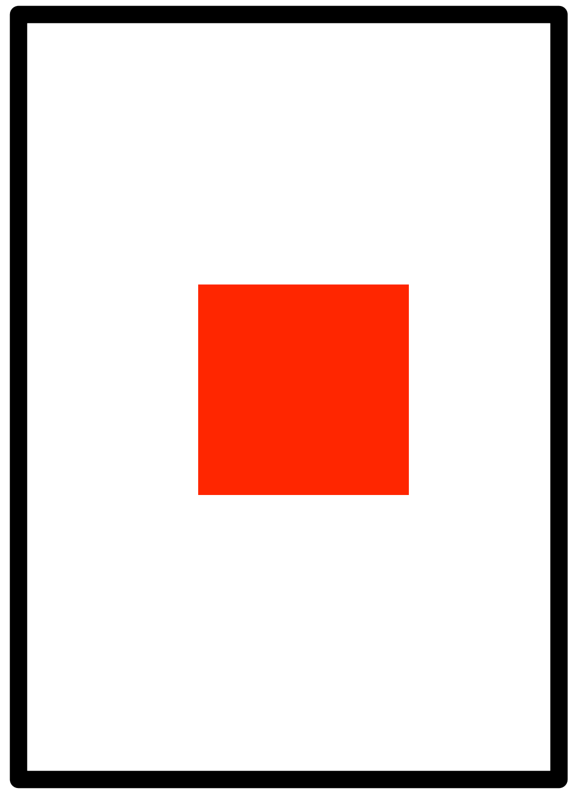


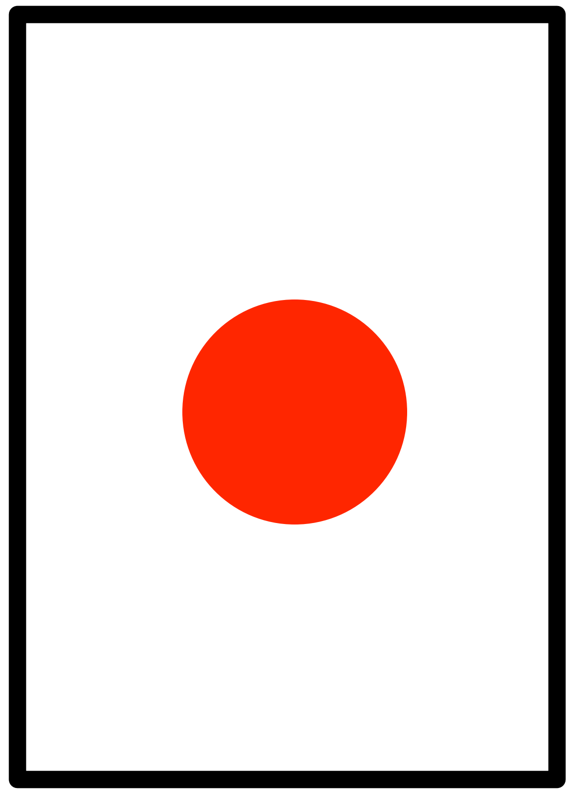




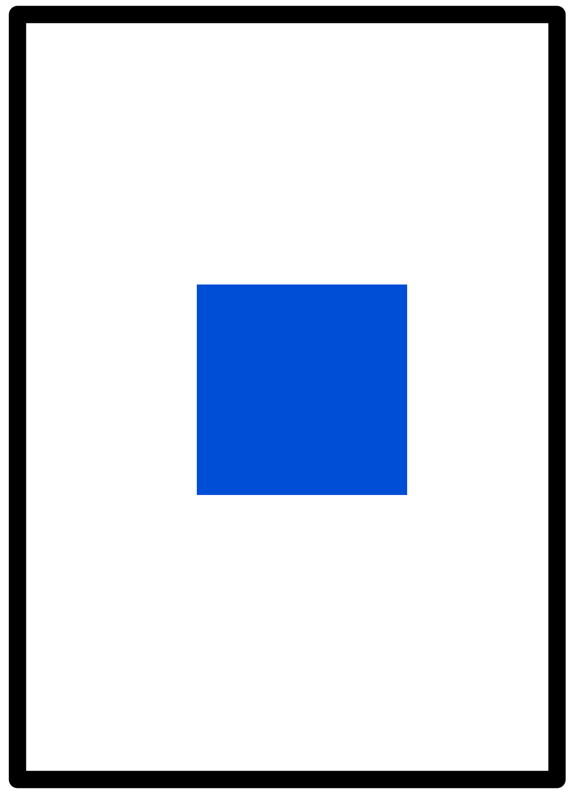


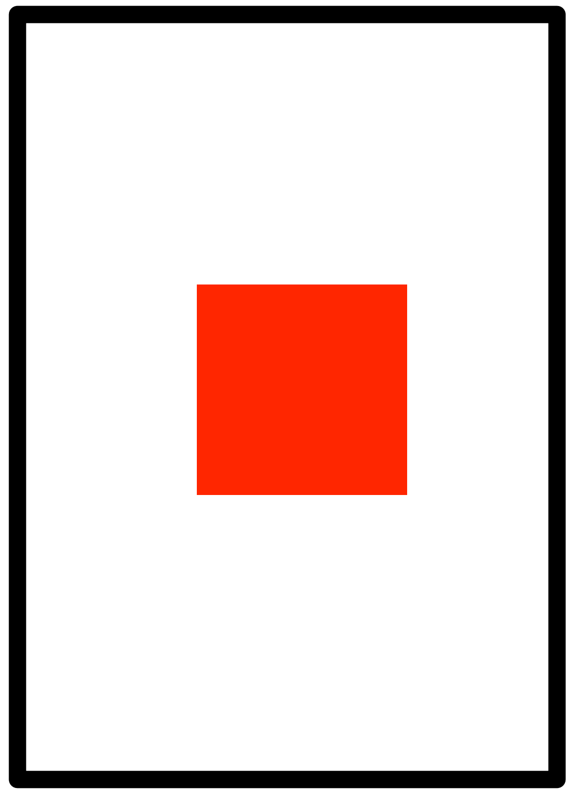


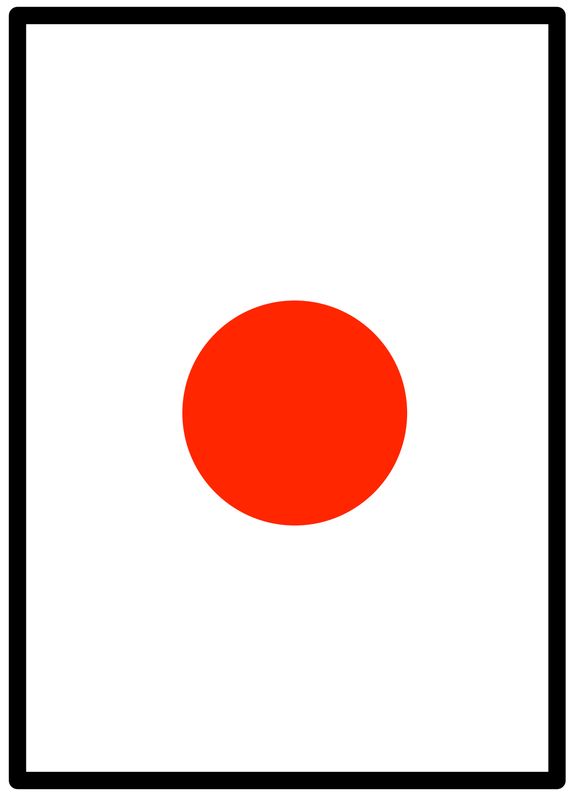


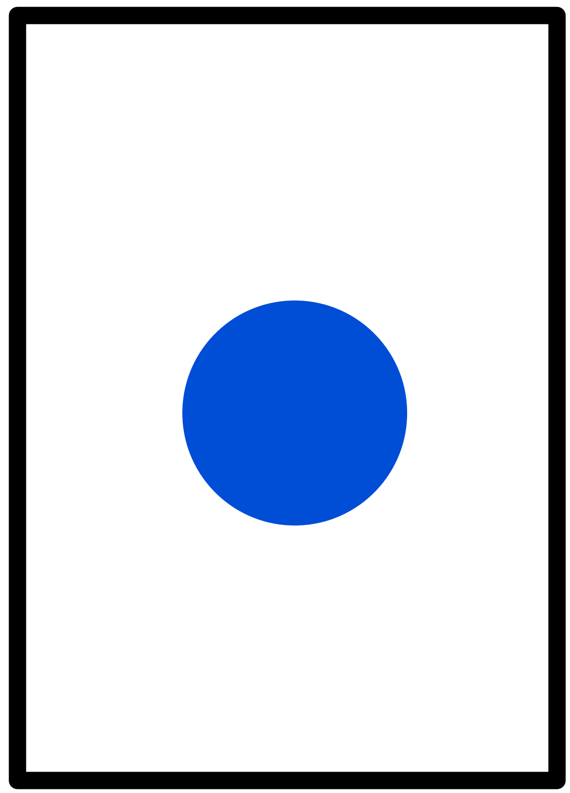


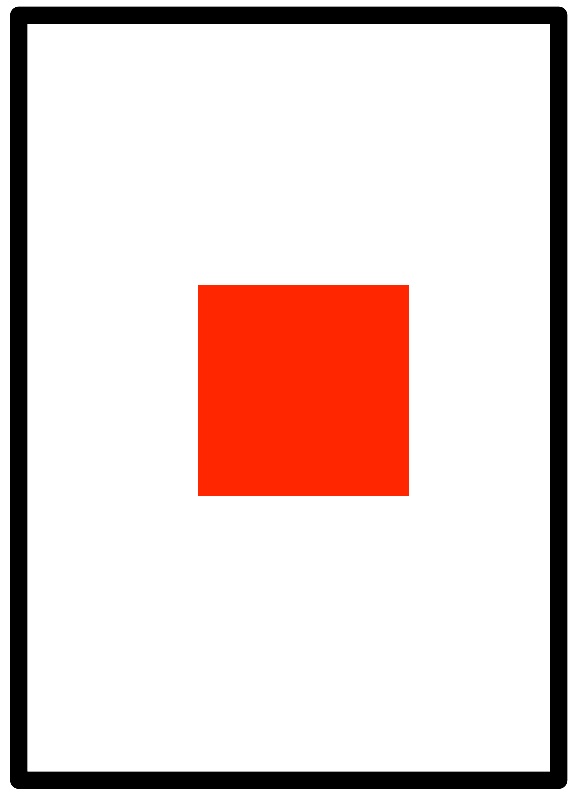
Rule: Shape











Wisconsin Card Sort Test

- Adults with prefrontal cortex damage (especially dorsolateral prefrontal cortex) behave like children on tasks that tap executive control, for example, on the **Wisconsin Card Sort Test** (WCST)

- They can learn the first sorting rule, but after the sorting rule changes, they **perseverate** – they continue to apply the first rule even though it has changed

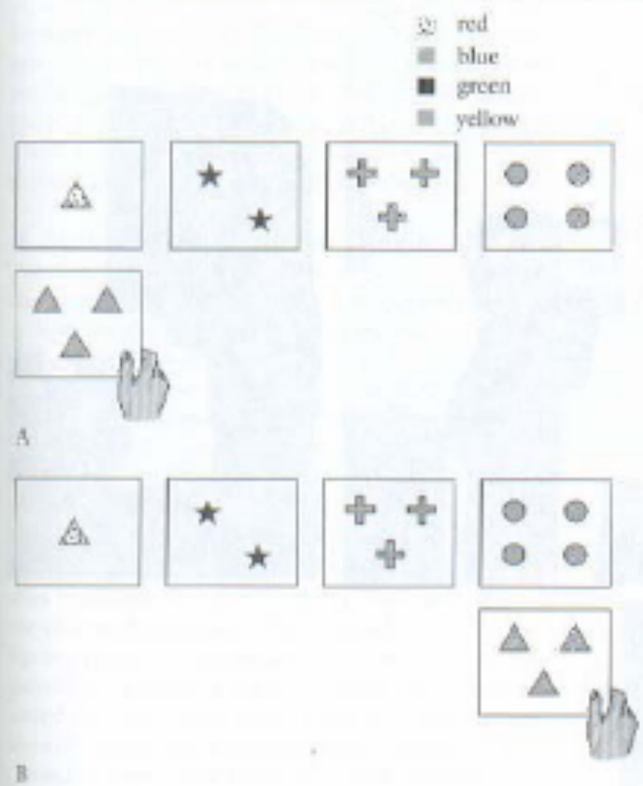


FIGURE 11.1 Two examples of sorting behavior on the Wisconsin Card Sorting Test (WCST). In this particular series of trials, the subject must sort on the basis of color. (A) An example of an incorrect sort because the individual matched the card on the basis of shape instead of color. (B) An example of a correct sort because the individual matched the card on the basis of color rather than shape or number.

Stimulus Response Selection

The Stroop Task

Recite the colour of the words you see

Green

Red

Yellow

Blue

Red

Green

Blue

Green

Yellow

Response Selection

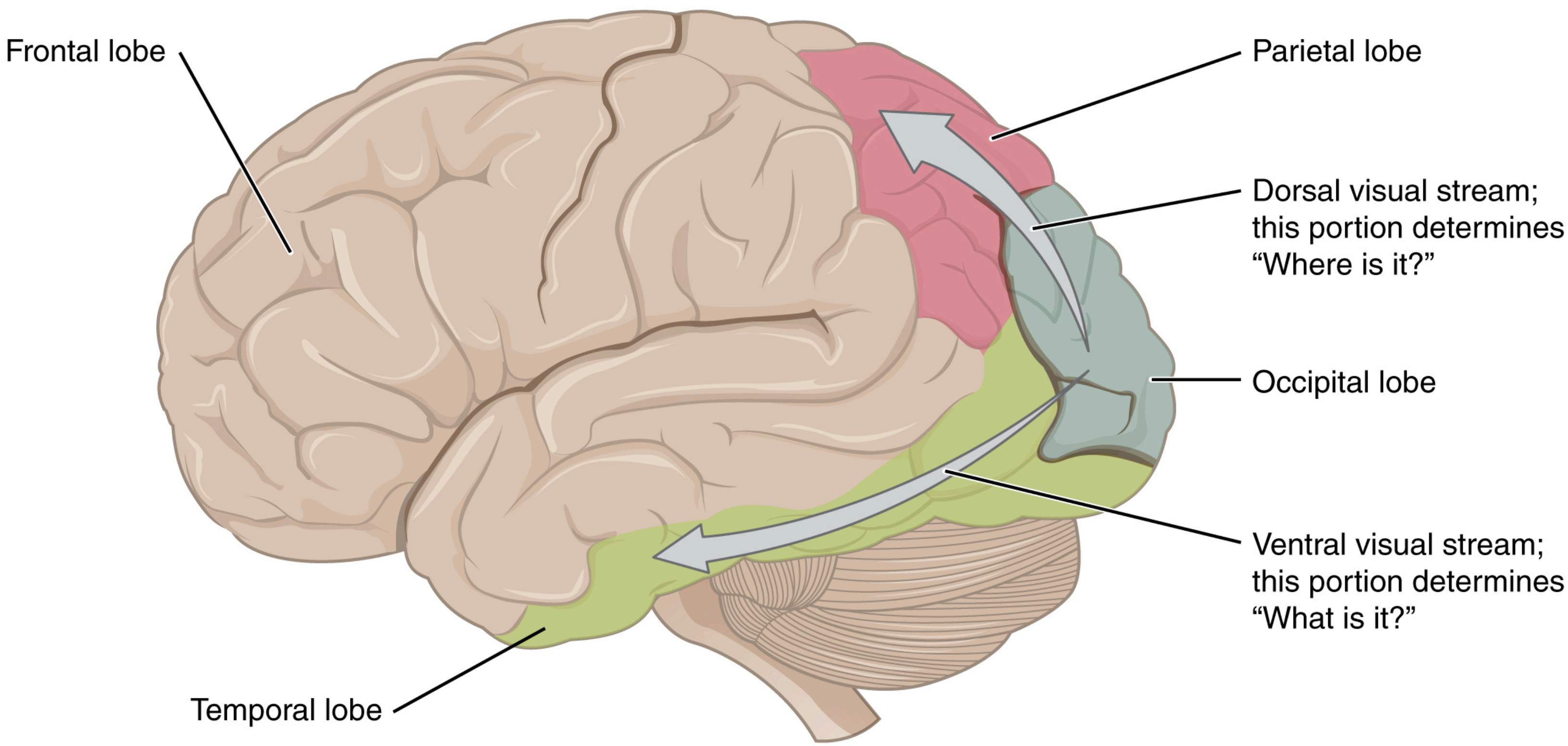
1. Stimulus Identification
2. Response Selection
3. Movement Planning
4. Movement Execution

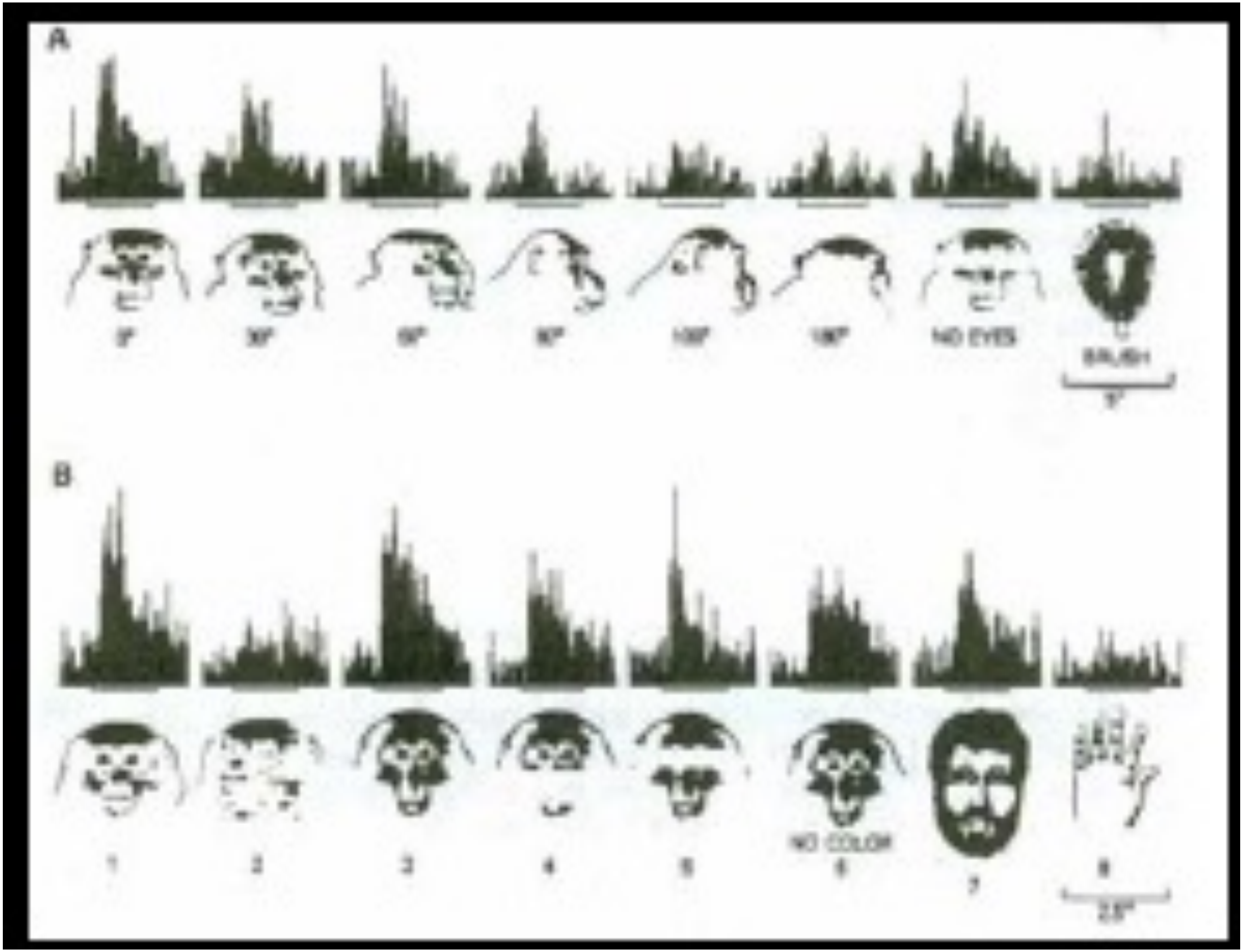
Stimulus Identification

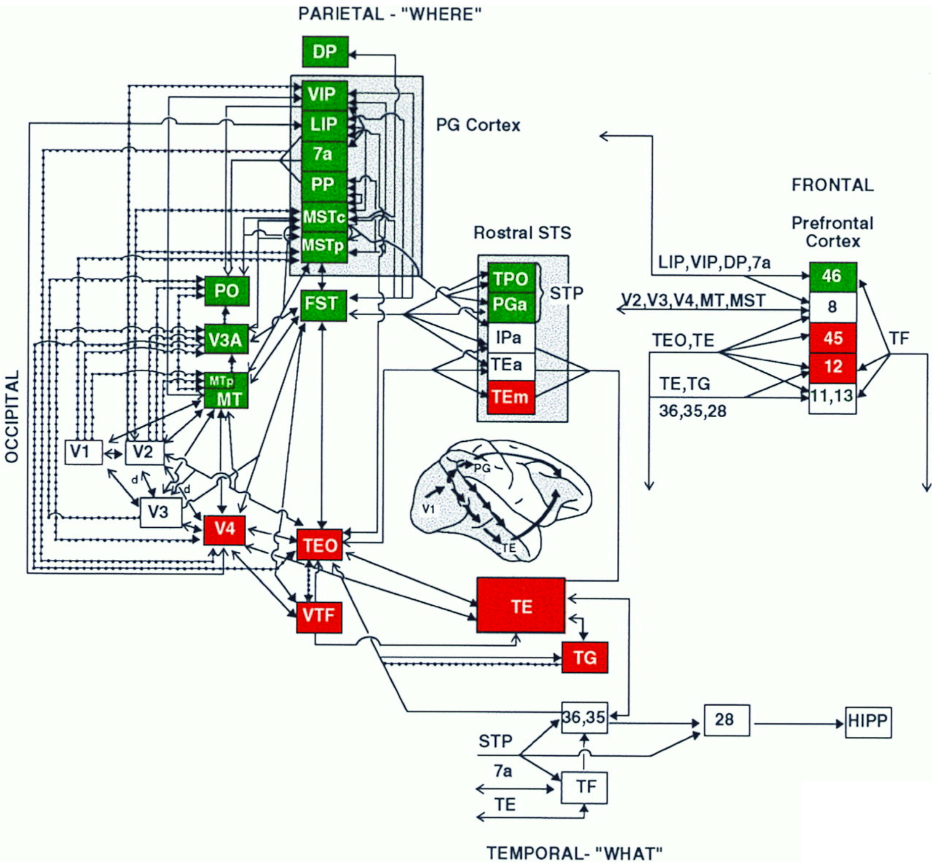
Stimulus Identification

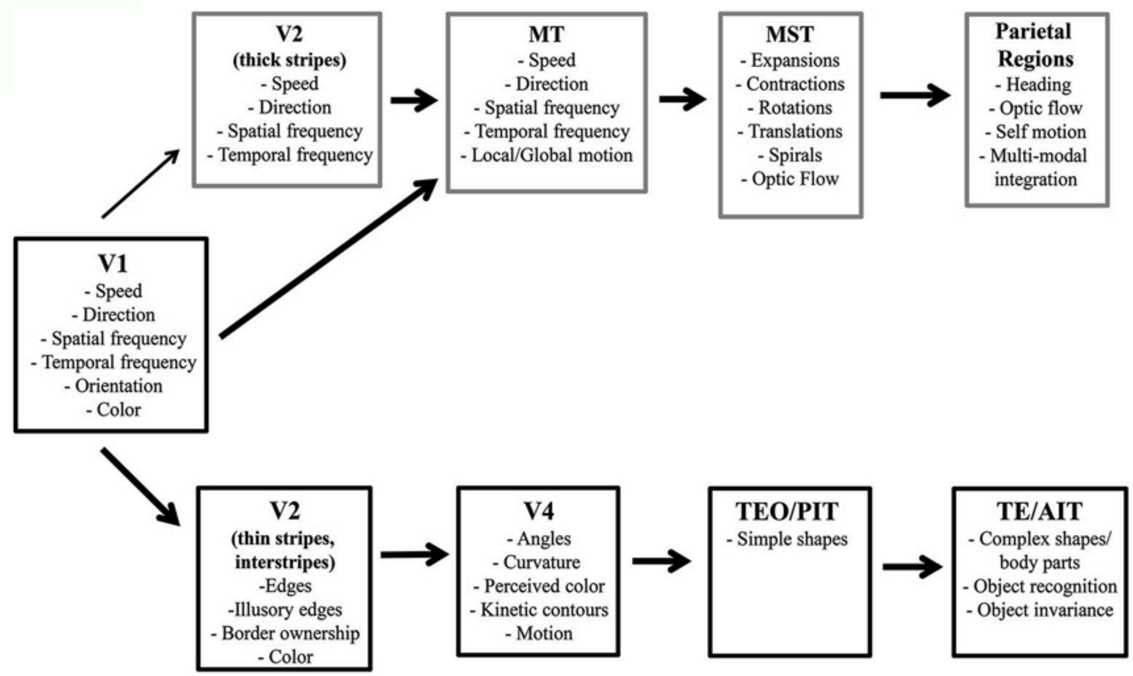
PERCEPTION

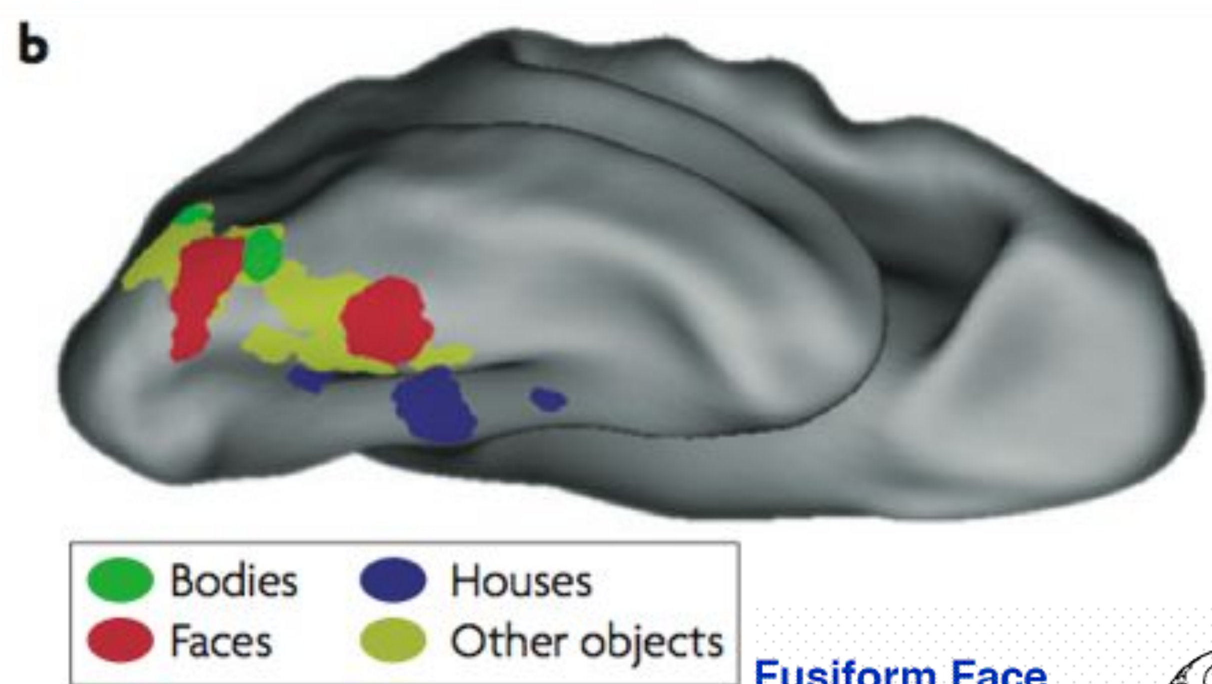
- i.e., the VENTRAL visual stream

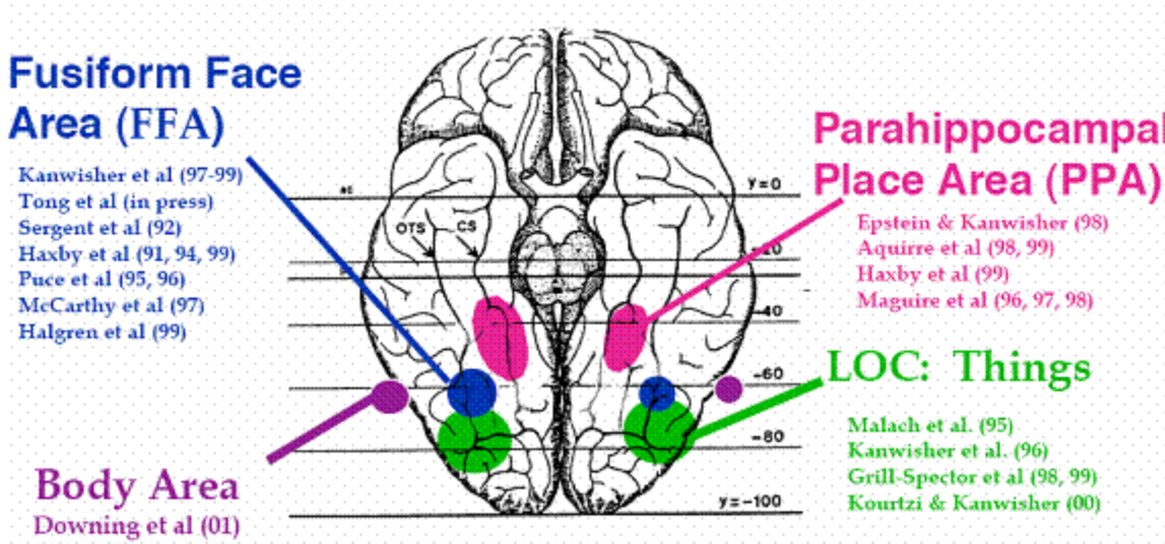



A
NO EYES
BRUSH
B
NO COLOR


PARIETAL - "WHERE"
DP
VIP
LIP
7a
PP
MSTc
MSTp
PG Cortex
PO
FST
V3A
MTp
MT
Rostral STS
TPO
PGa
IPa
TEa
TEm
STP
FRONTAL
Prefrontal Cortex
LIP,VIP,DP,7a
V2,V3,V4,MT,MST
TEO,TE
TE,TG
36,35,28
46
8
45
12
11,13
TF
OCCIPITAL
V1
V2
V3
V4
TEO
TE
VTF
TG
36,35
28
HIPP
STP
7a
TE
TF
TEMPORAL- "WHAT"

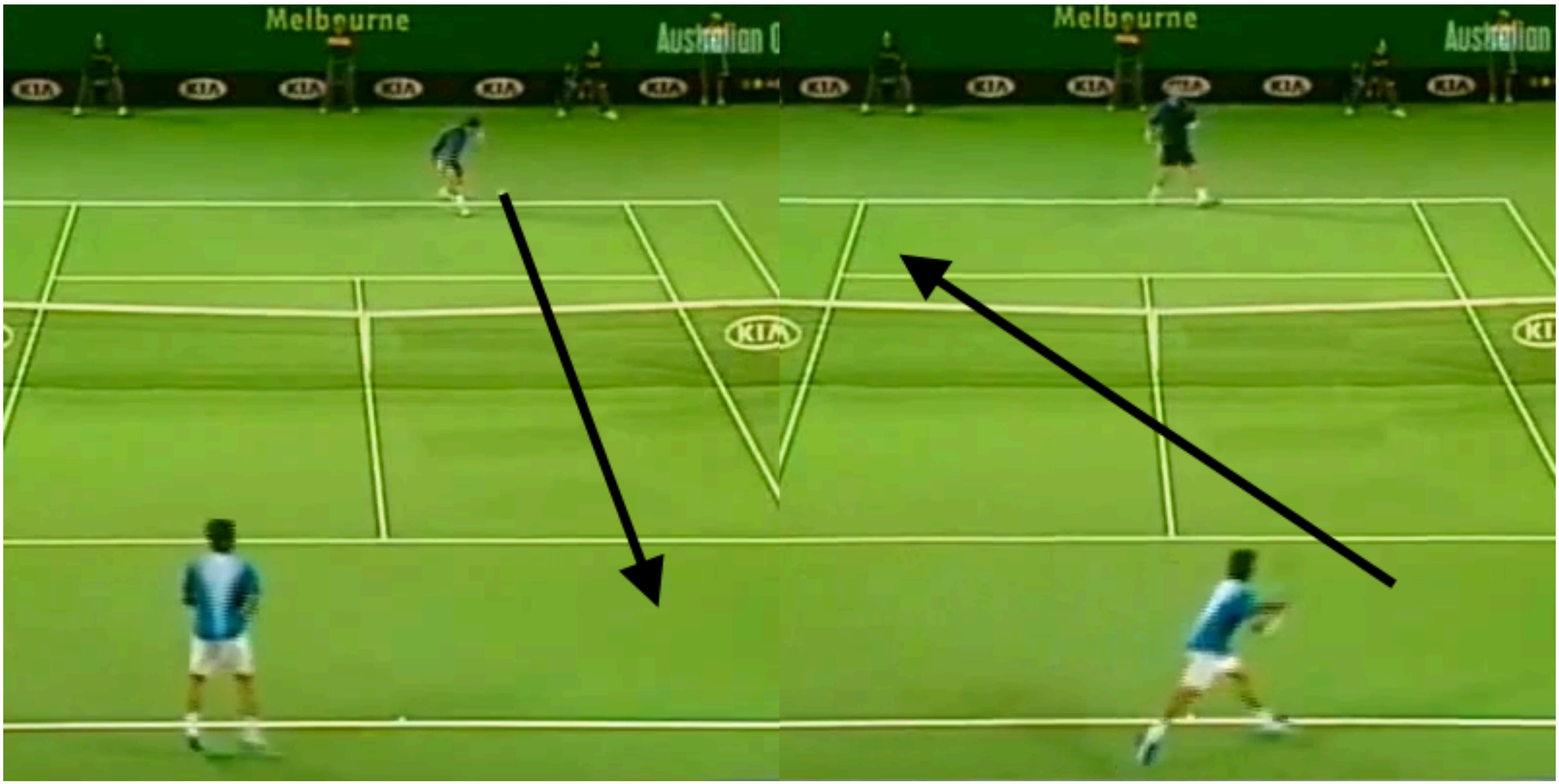

V1
- Speed
- Direction
- Spatial frequency
- Temporal frequency
- Orientation
- Color
V2
(thick stripes)
- Speed
- Direction
- Spatial frequency
- Temporal frequency
MT
- Speed
- Direction
- Spatial frequency
- Temporal frequency
- Local/Global motion
MST
- Expansions
- Contractions
- Rotations
- Translations
- Spirals
- Optic Flow
Parietal Regions
- Heading
- Optic flow
- Self motion
- Multi-modal integration
V2
(thin stripes, interstripes)
-Edges
-Illusory edges
- Border ownership
- Color
V4
- Angles
- Curvature
- Perceived color
- Kinetic contours
- Motion
TEO/PIT
- Simple shapes
TE/AIT
- Complex shapes/ body parts
- Object recognition
- Object invariance





There are whole courses on PERCEPTION, i.e., PSYC 317B
Other than what we have discussed here we will make the assumption that we can accurately identify movement targets

Response Selection

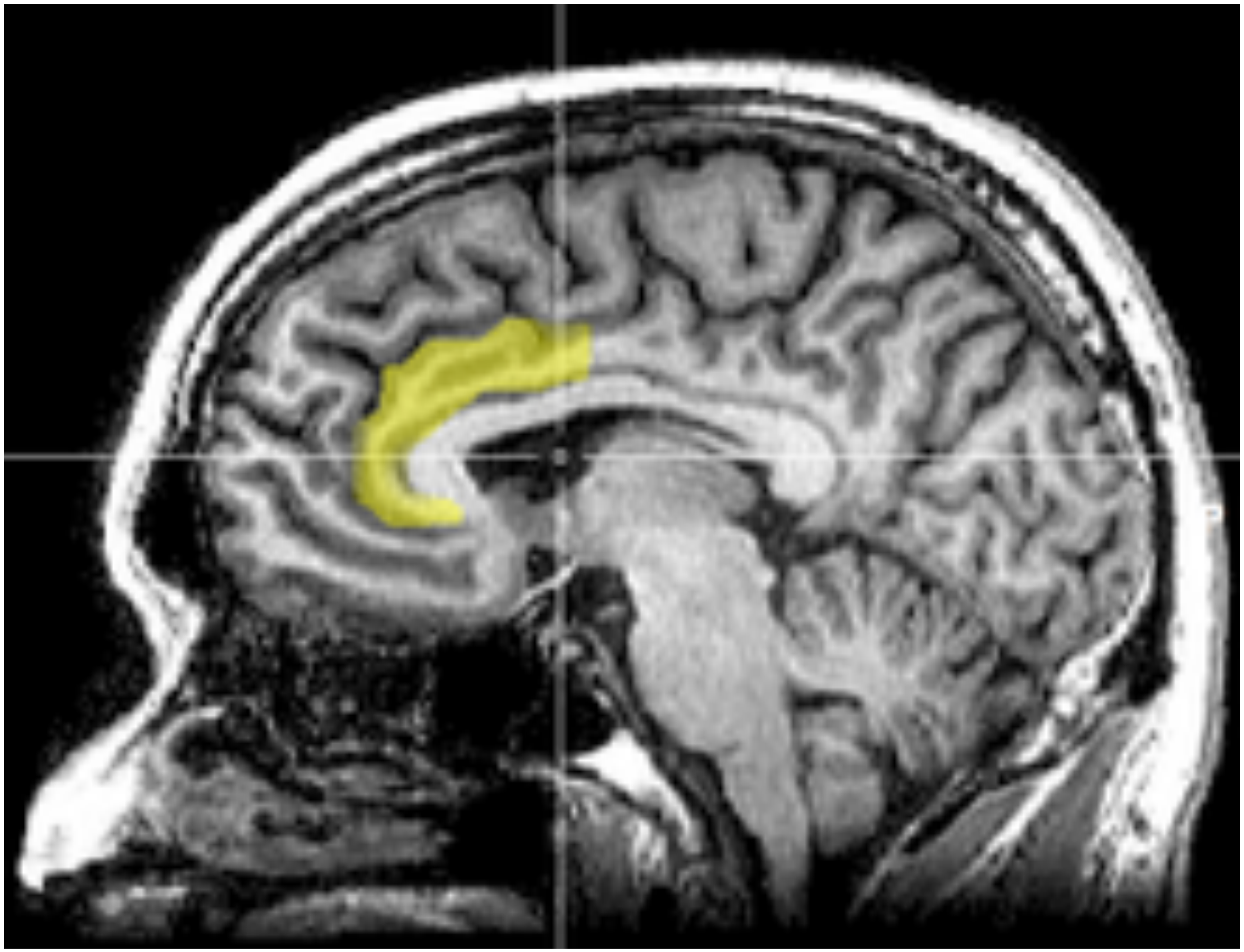


Response Selection is a form of DECISION MAKING

Thus, Markov Decision Making (MDM) rules apply:

1. Always choose the highest value option (Exploitation)
2. Sometimes choose a lower value option (Exploration)

A Neural Centre for Response Selection?



Anterior Cingulate Cortex

Executive Control and Attention

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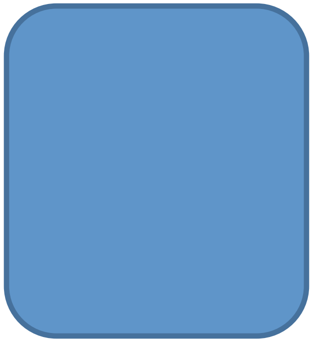

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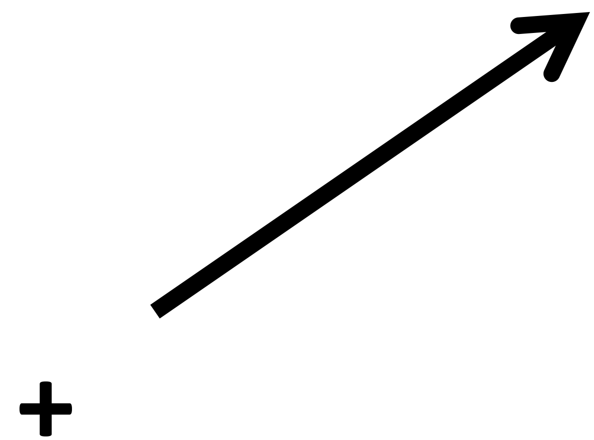
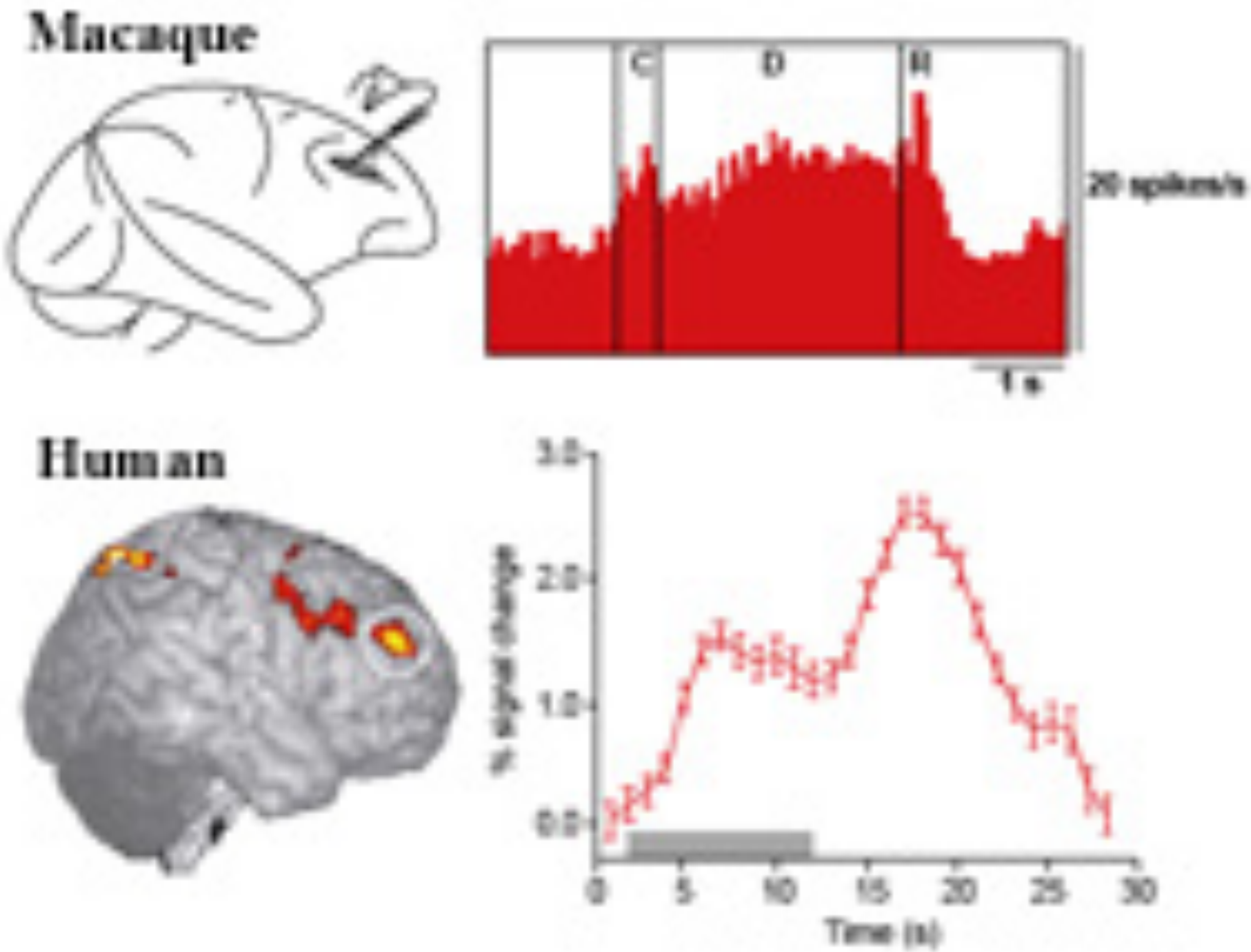
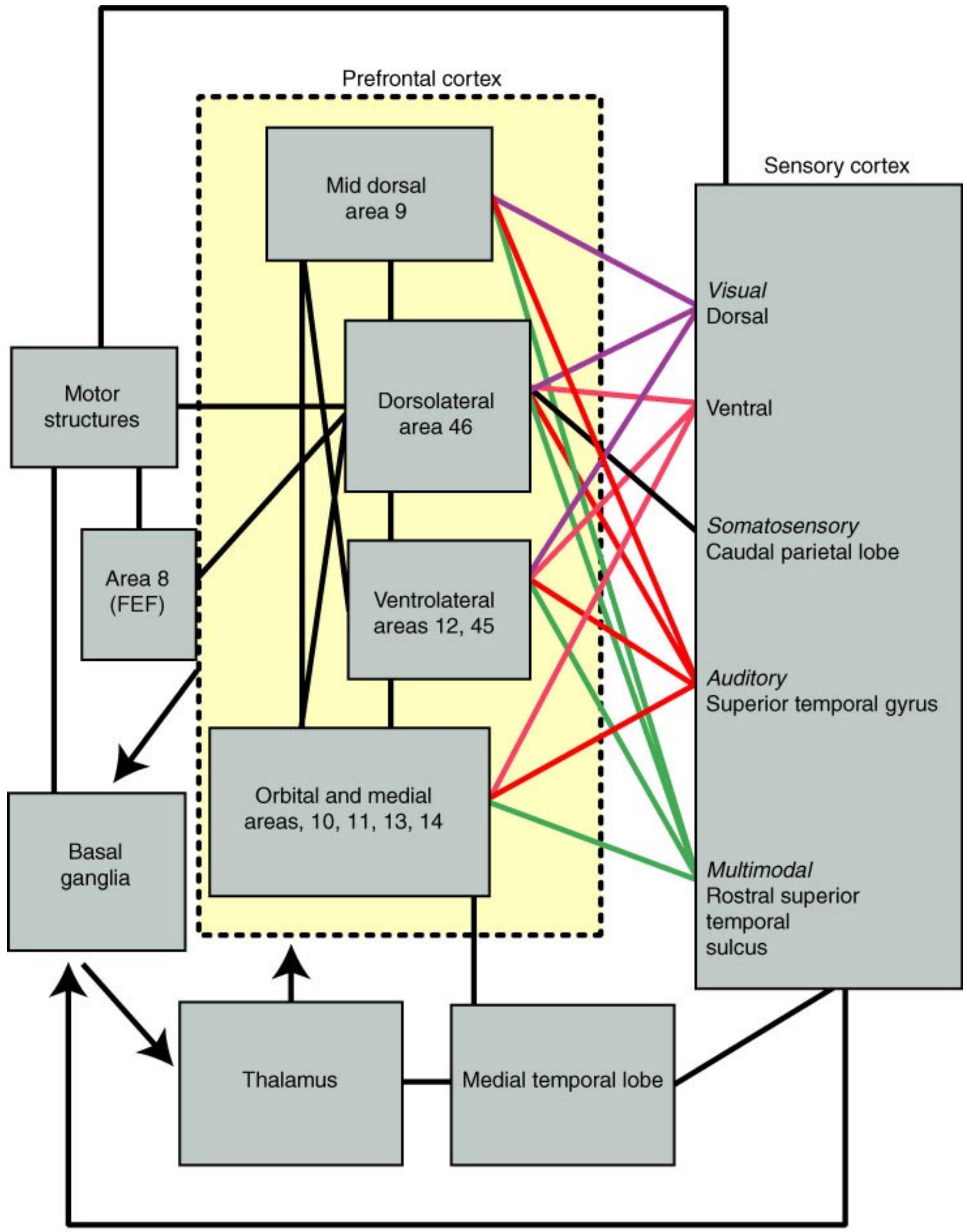


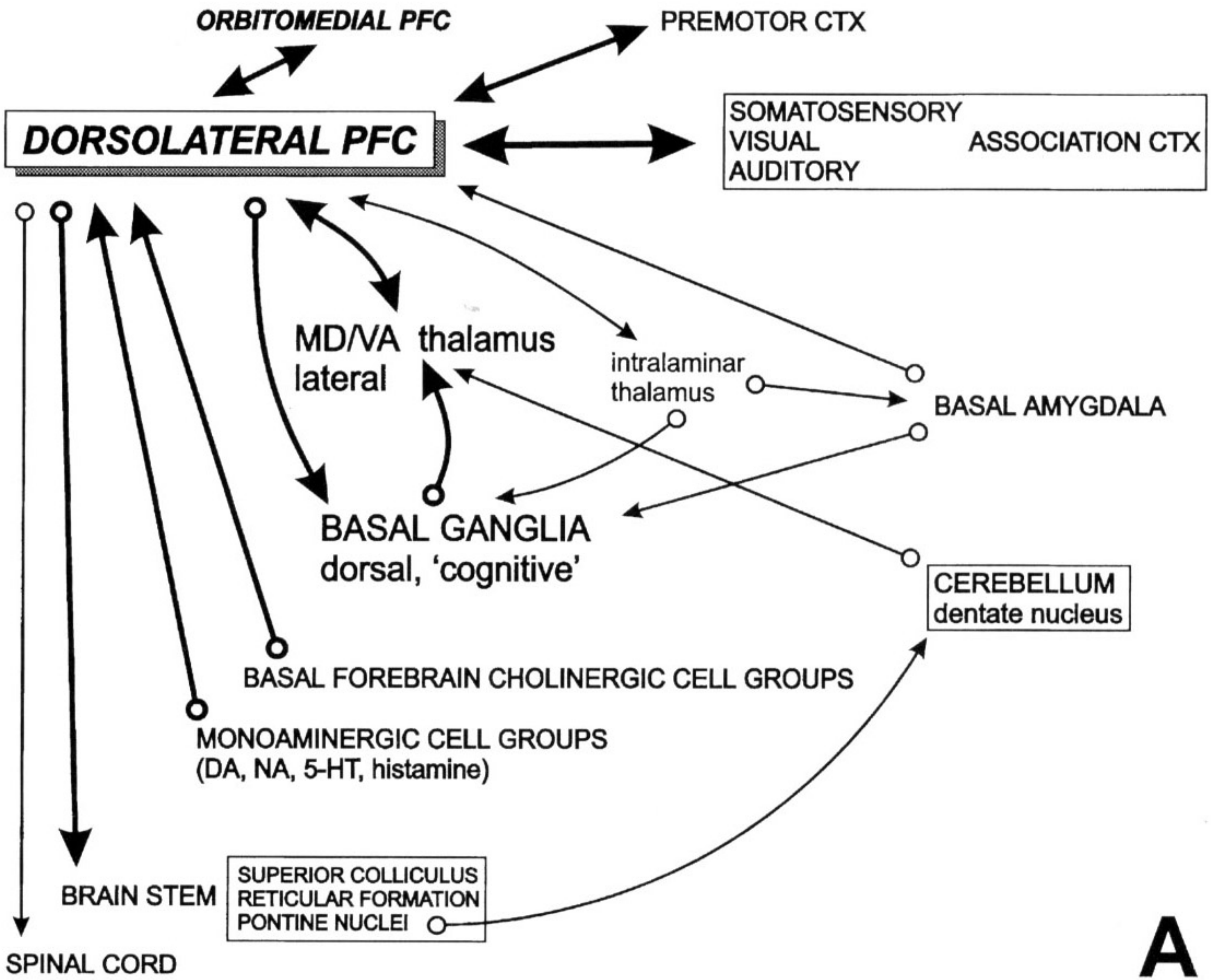


Continuous neuronal firing in prefrontal cortex is necessary to maintain attention

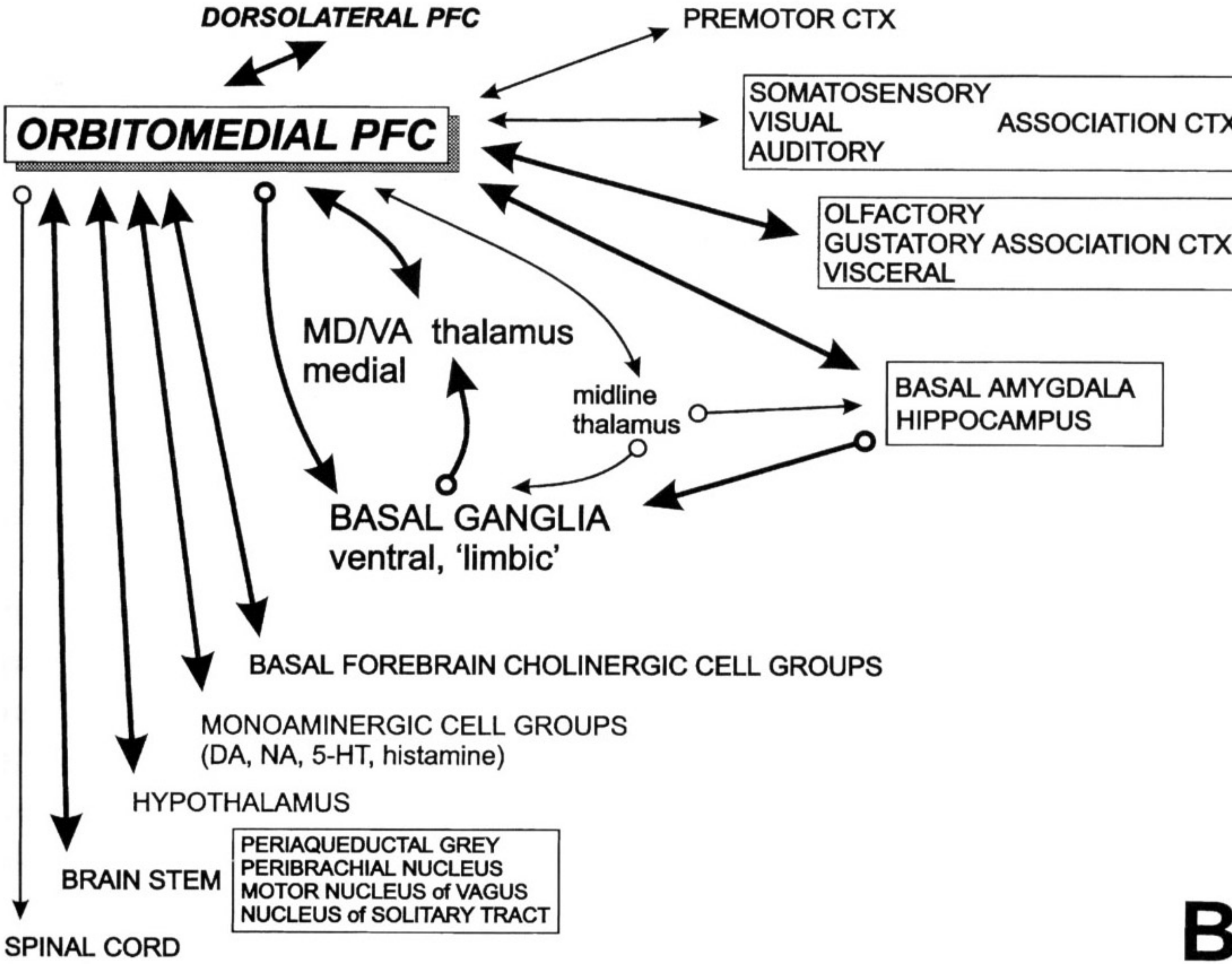
Why the Prefrontal Cortex?

CONNECTIONS OF THE FRONTAL CORTEX





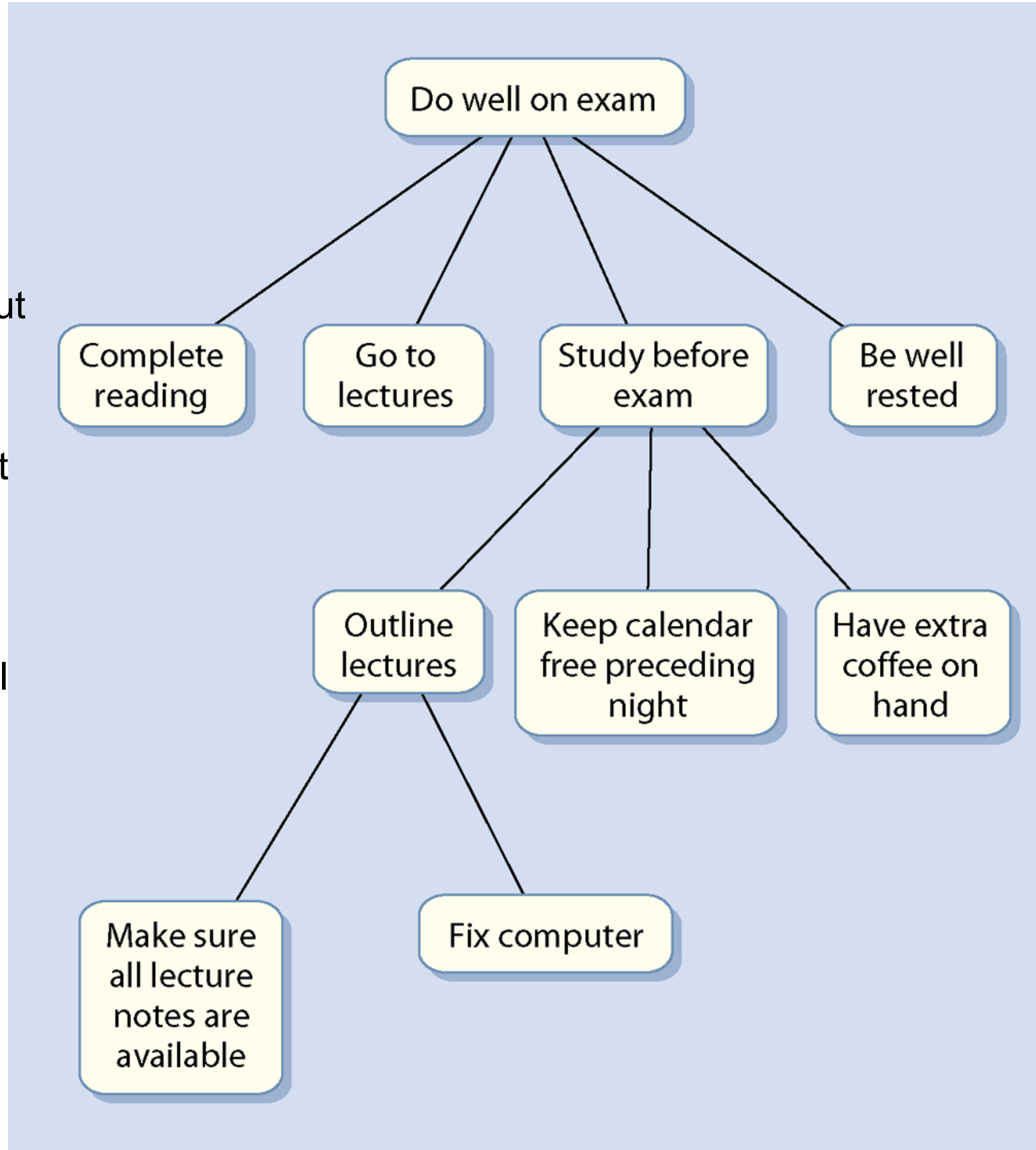
ORBITOMEDIAL PFC
PREMOTOR CTX
DORSOLATERAL PFC
SOMATOSENSORY
VISUAL
AUDITORY
ASSOCIATION CTX
MD/VA thalamus
lateral
intralaminar
thalamus
BASAL AMYGDALA
BASAL GANGLIA
dorsal, 'cognitive'
CEREBELLUM
dentate nucleus
BASAL FOREBRAIN CHOLINERGIC CELL GROUPS
MONOAMINERGIC CELL GROUPS
(DA, NA, 5-HT, histamine)
BRAIN STEM
SUPERIOR COLLICULUS
RETICULAR FORMATION
PONTINE NUCLEI
SPINAL CORD
A



DORSOLATERAL PFC
PREMOTOR CTX
ORBITOMEDIAL PFC
SOMATOSENSORY
VISUAL
AUDITORY
ASSOCIATION CTX
OLFACTORY
GUSTATORY ASSOCIATION CTX
VISCERAL
MD/VA thalamus
medial
midline
thalamus
BASAL AMYGDALA
HIPPOCAMPUS
BASAL GANGLIA
ventral, 'limbic'
BASAL FOREBRAIN CHOLINERGIC CELL GROUPS
MONOAMINERGIC CELL GROUPS
(DA, NA, 5-HT, histamine)
HYPOTHALAMUS
BRAIN STEM
PERIAQUEDUCTAL GREY
PERIBRACHIAL NUCLEUS
MOTOR NUCLEUS of VAGUS
NUCLEUS of SOLITARY TRACT
SPINAL CORD
B

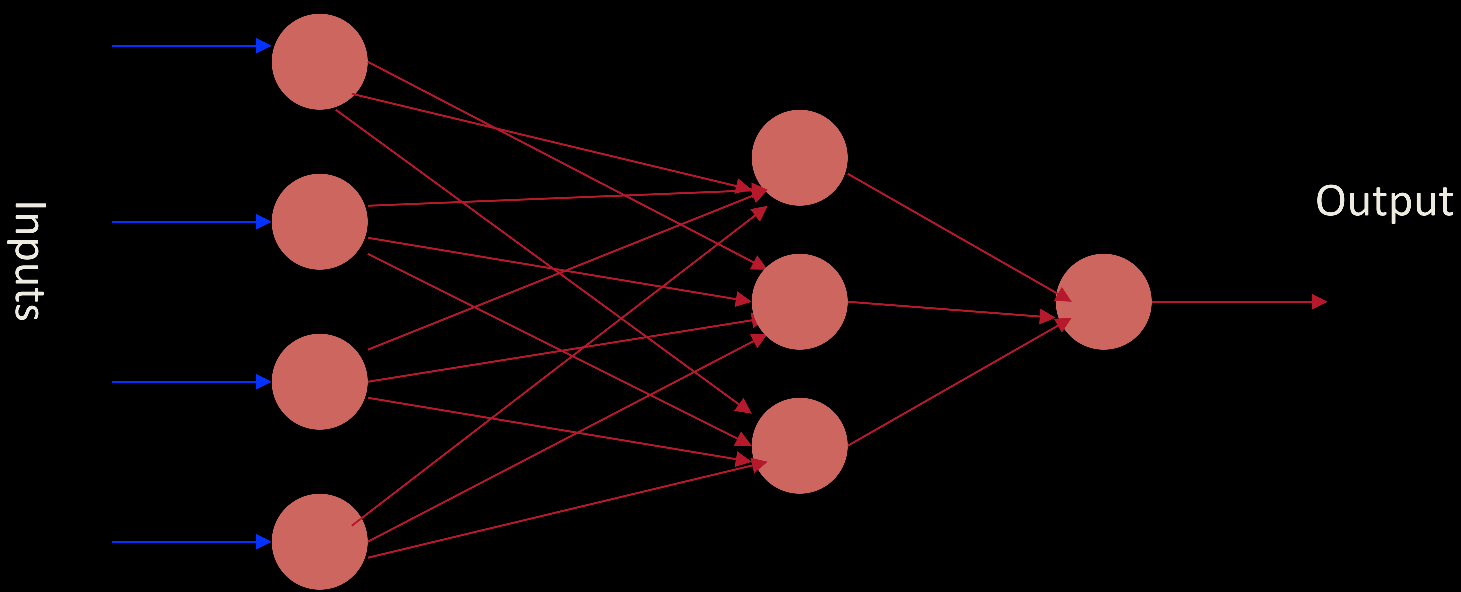
GOAL DIRECTED BEHAVIOR

1. Planning: identify goals, develop subgoals.
2. Receive information about goals and means. Rule learning. Reward
3. Selection of task relevant information- selection of responses (focusing, attention)
4. Determine what temporal order is required to achieve the subgoals
5. Switching tasks, when necessary
6. Monitoring progress



Computational Models of Cognitive Control

Artificial Neural Networks



An artificial neural network is composed of many artificial neurons that are linked together according to a specific network architecture. The objective of the neural network is to transform the inputs into meaningful outputs.

Why?

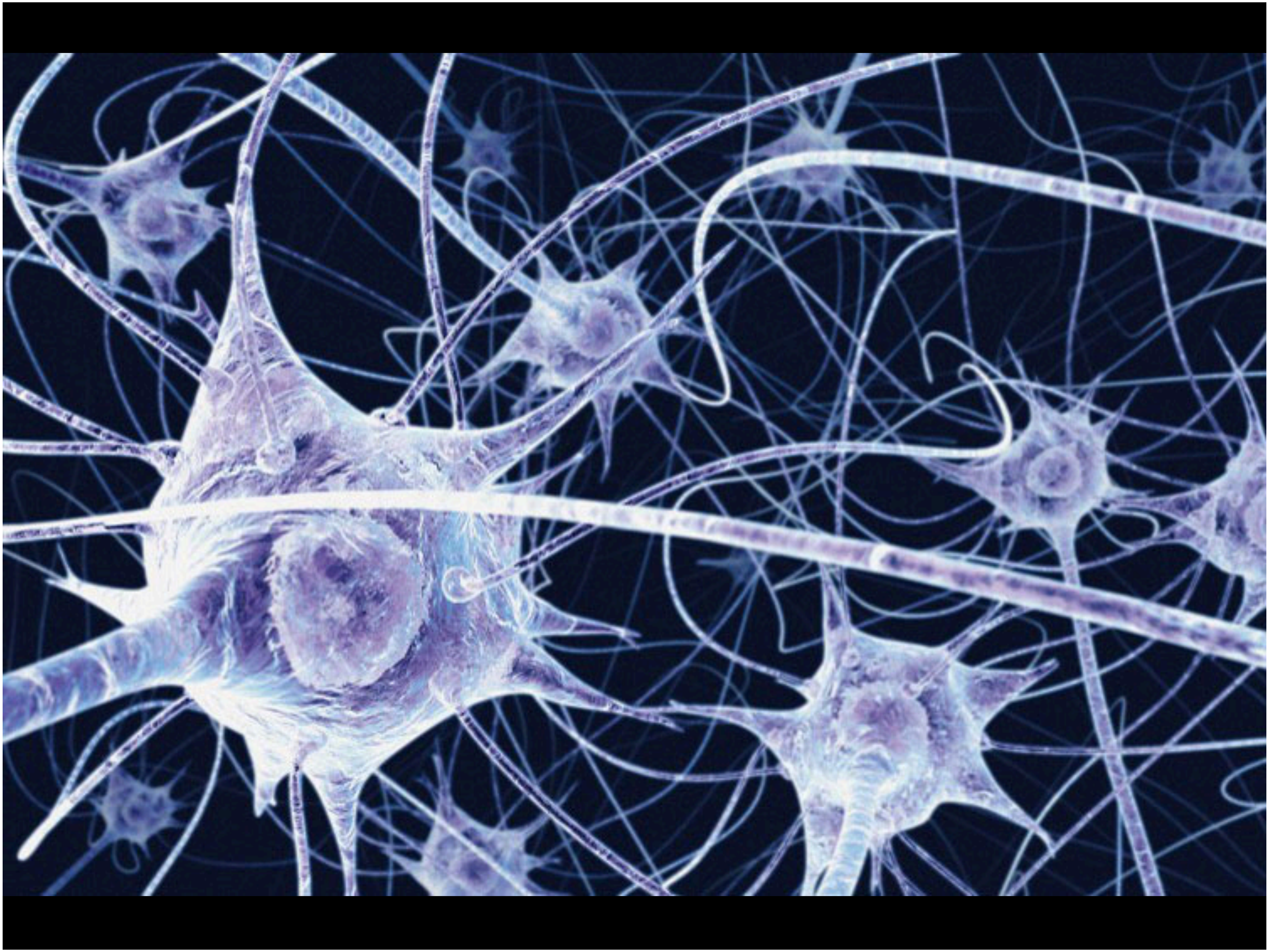
Biological Inspiration

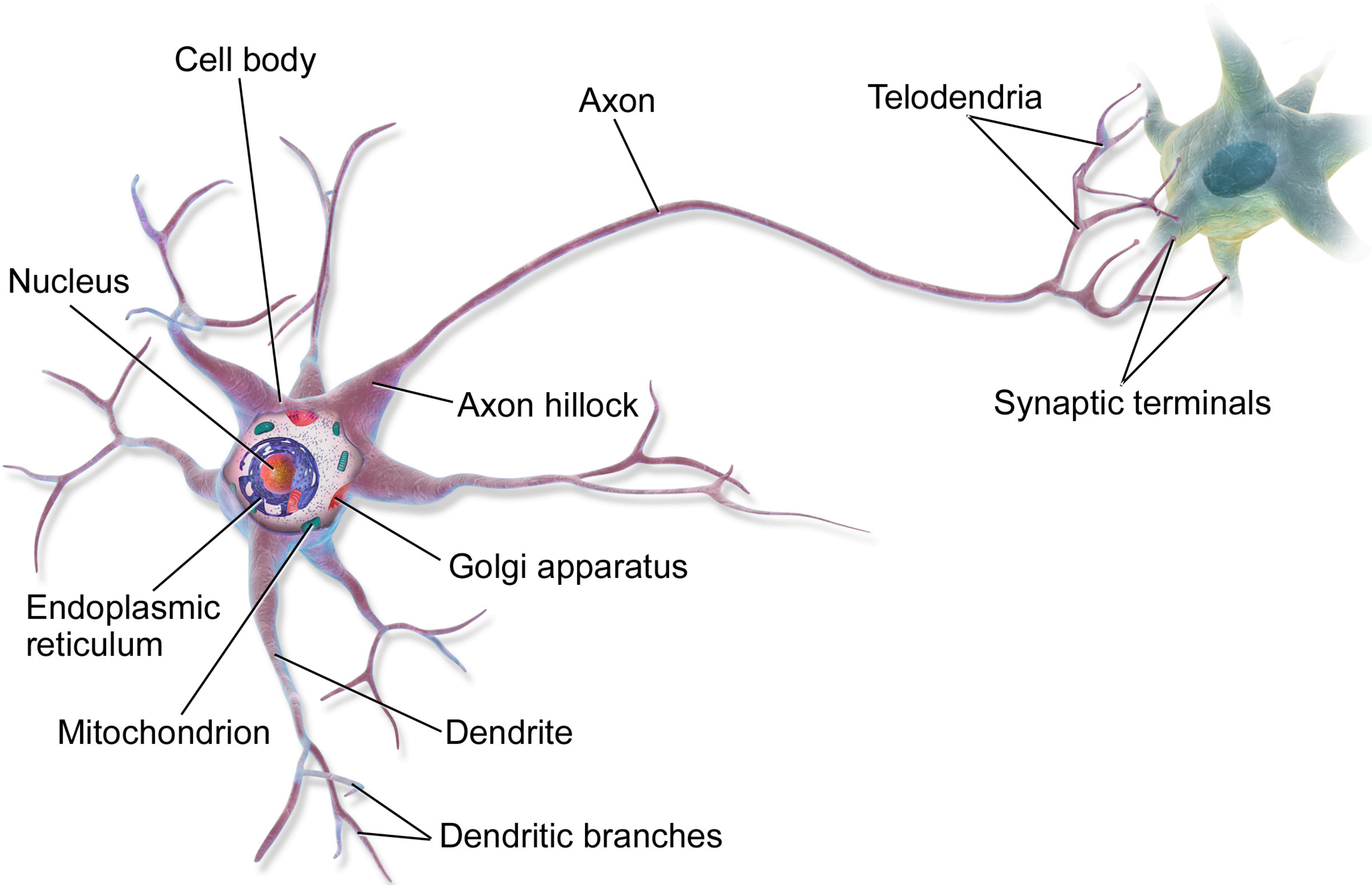
Animals are able to react adaptively to changes in their external and internal environment, and they use their nervous system to perform these behaviours.

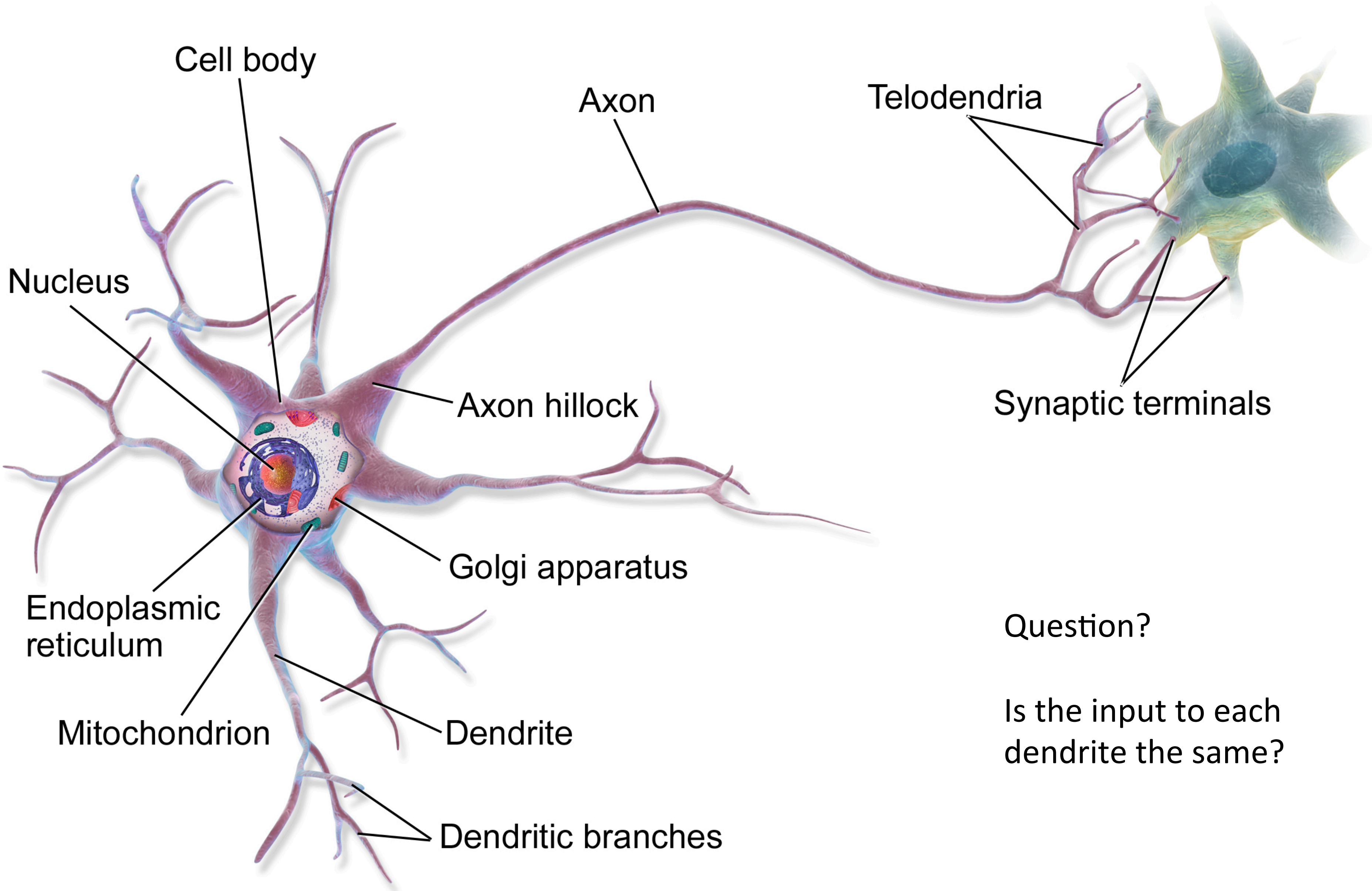
An appropriate model/simulation of the nervous system should be able to produce similar responses and behaviours in artificial systems.

Goals:
1. Understanding
2. Prediction
3. To Do Jobs: Classification, Identification, Prediction

The Basics

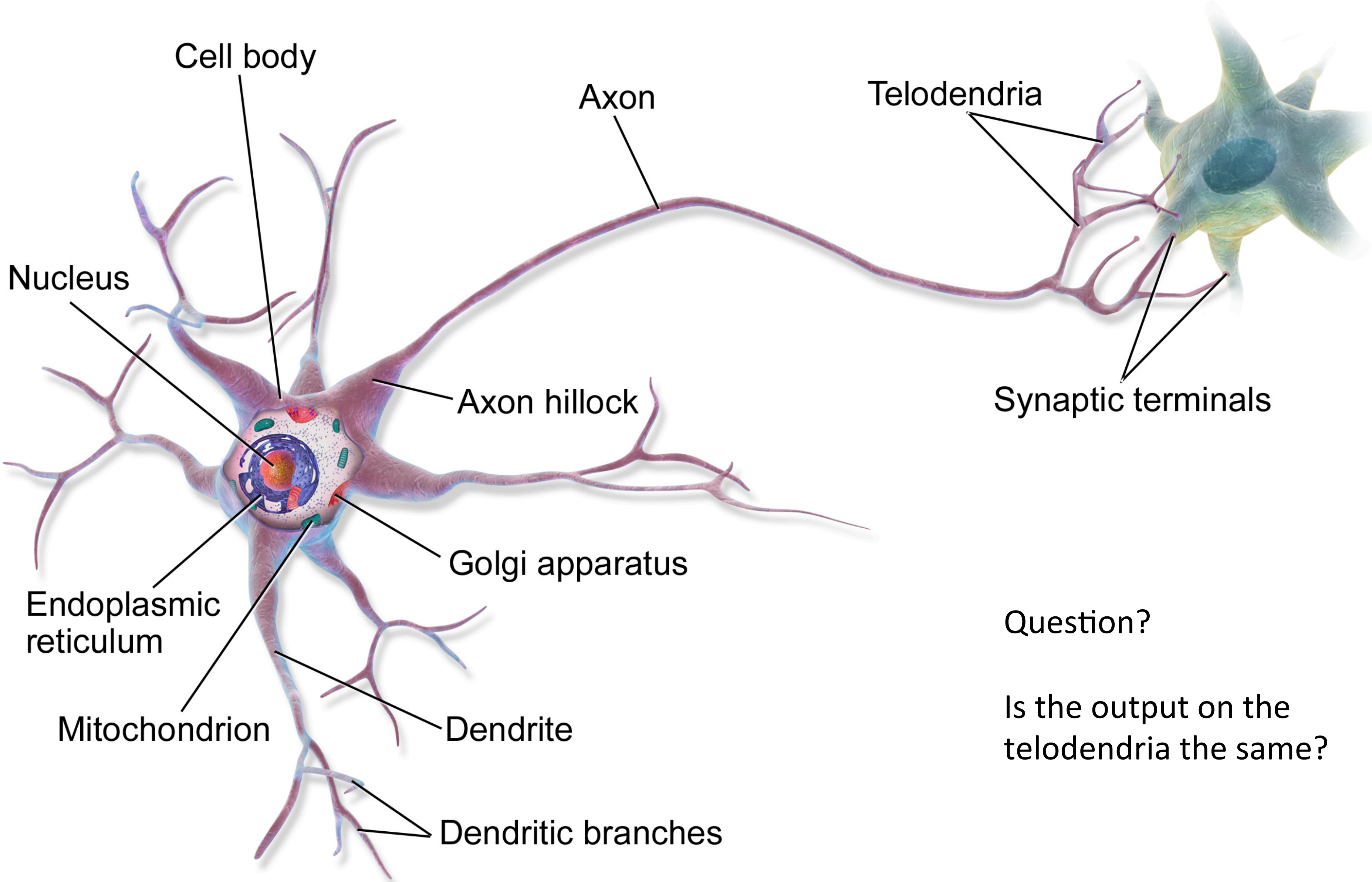



Cell body
Axon
Telodendria
Nucleus
Axon hillock
Synaptic terminals
Golgi apparatus
Endoplasmic
reticulum
Mitochondrion
Dendrite
Dendritic branches



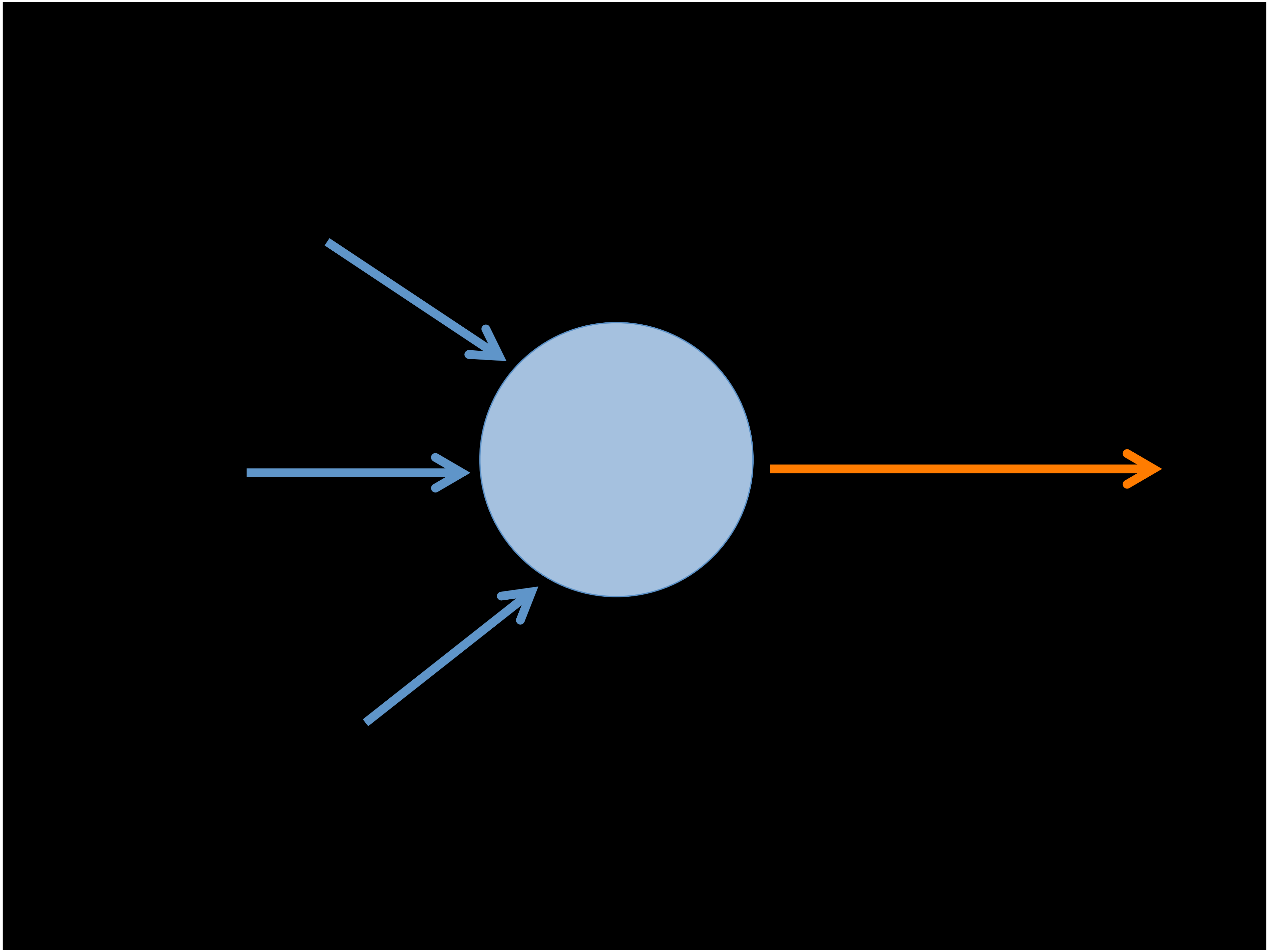
Question?

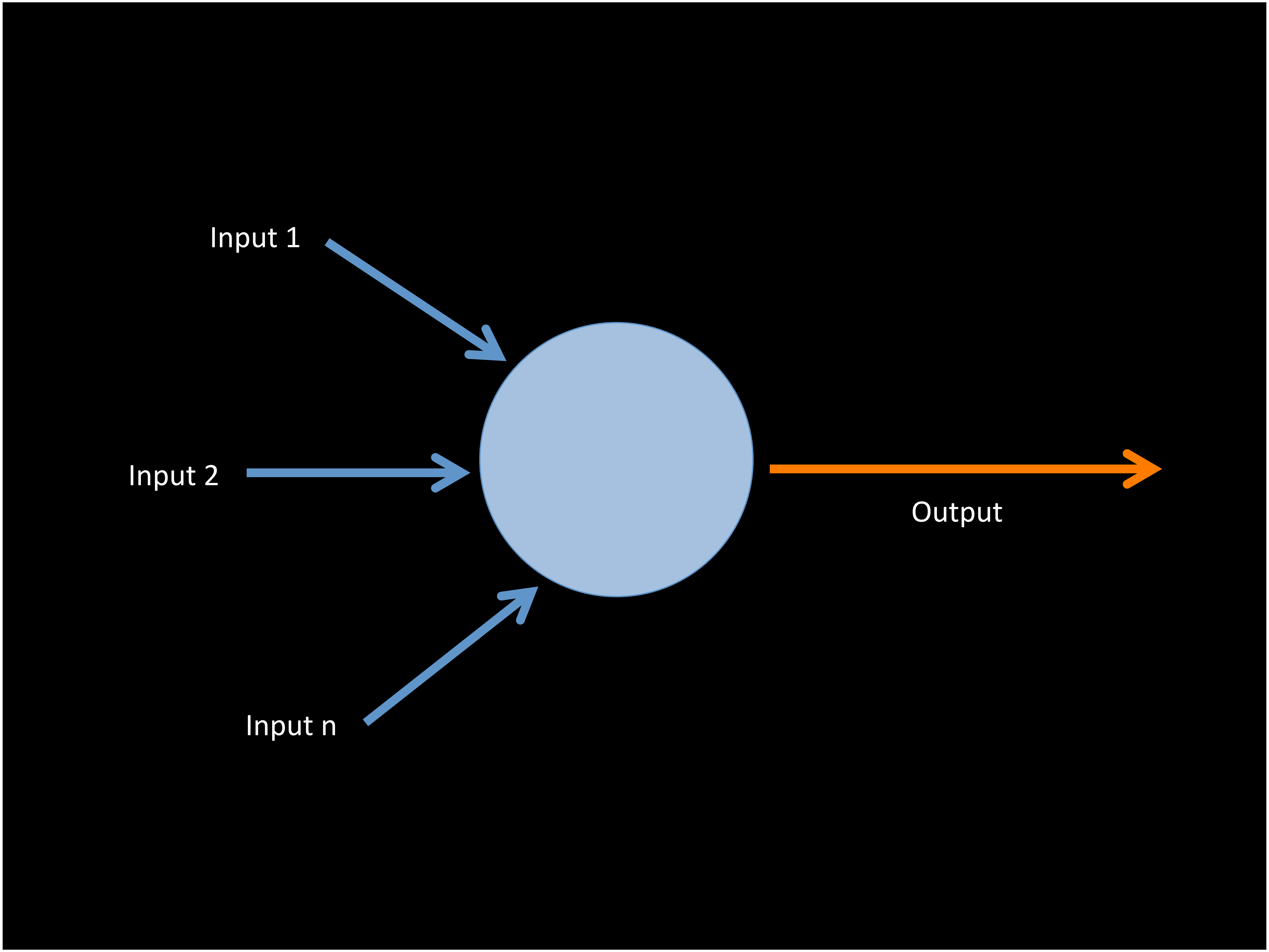
Is the input to each dendrite the same?



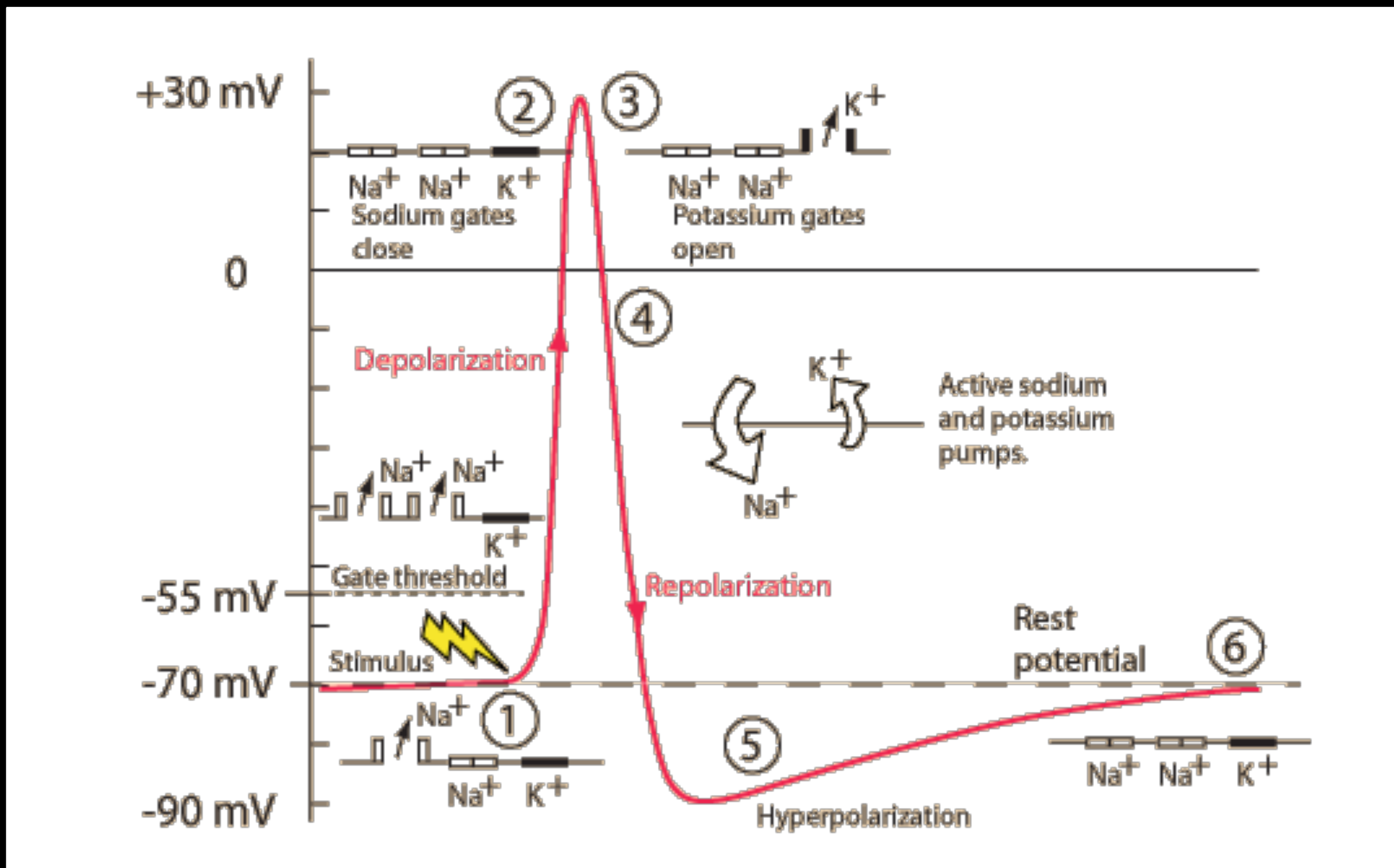
Question?

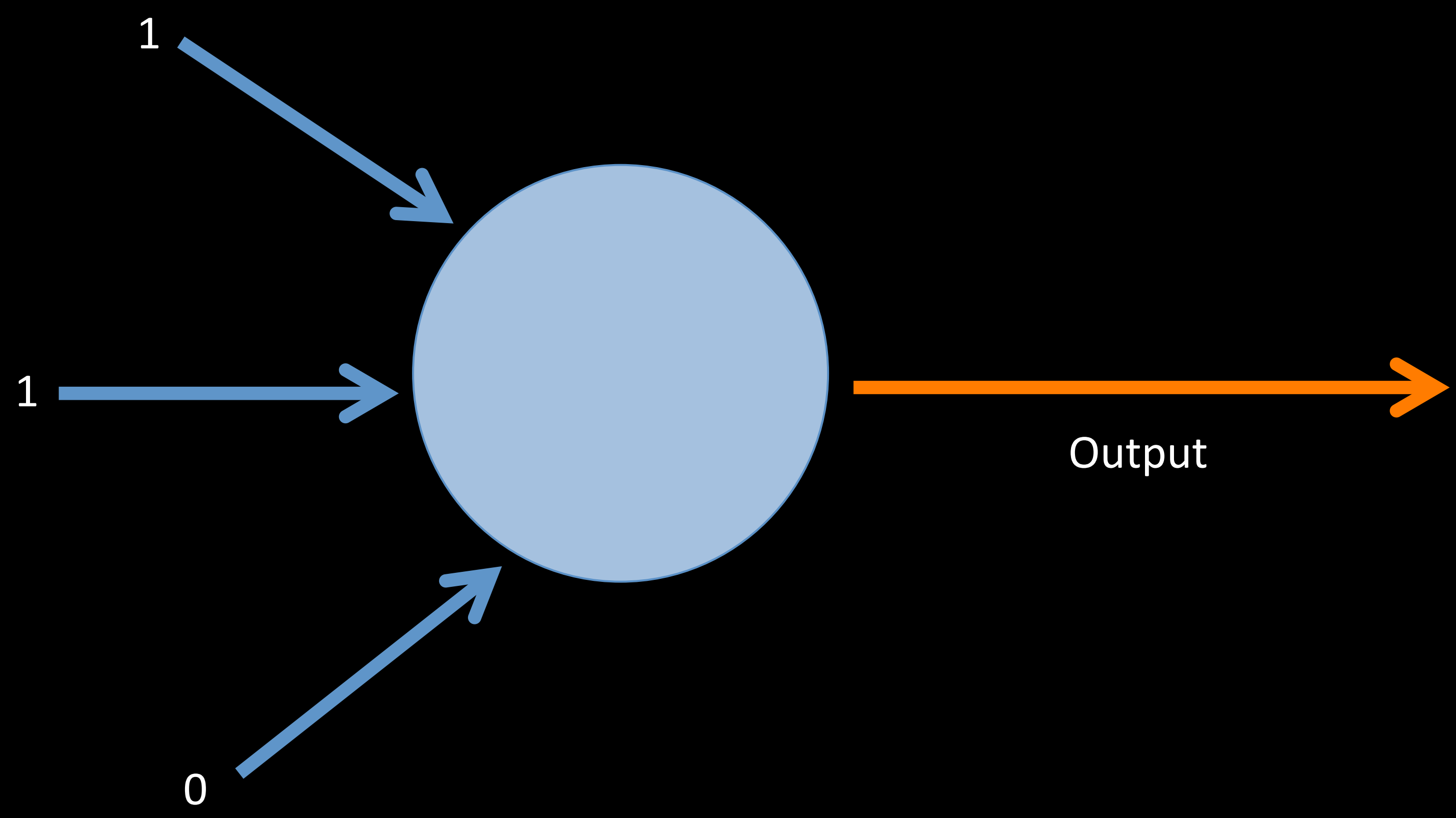
Is the output on the telodendria the same?



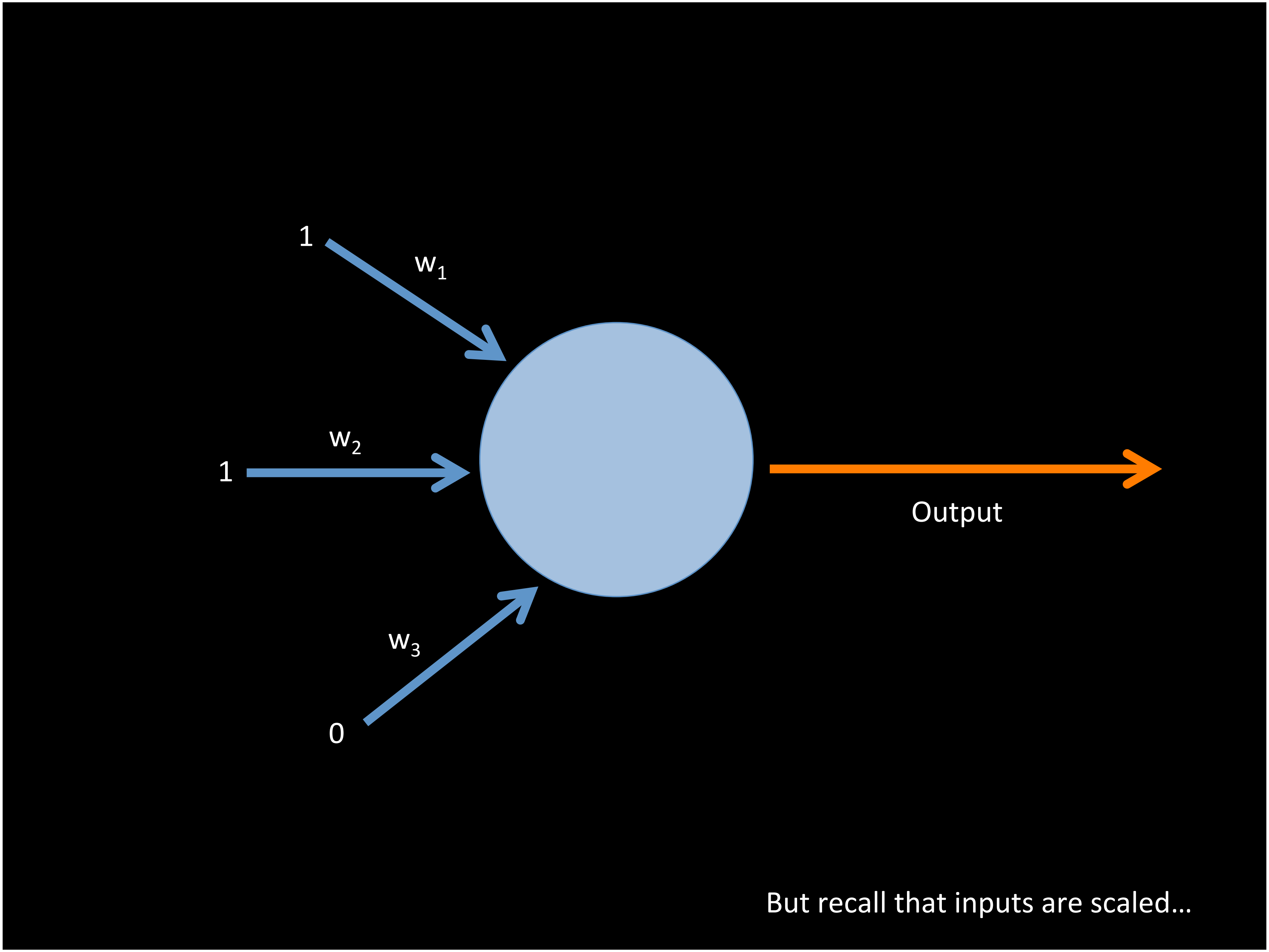

Input 1
Input 2
Input n
Output

So what makes a neuron fire?





But recall that inputs are scaled…


1
w1
1
w2
0
w3
Output
But recall that inputs are scaled…

The Input

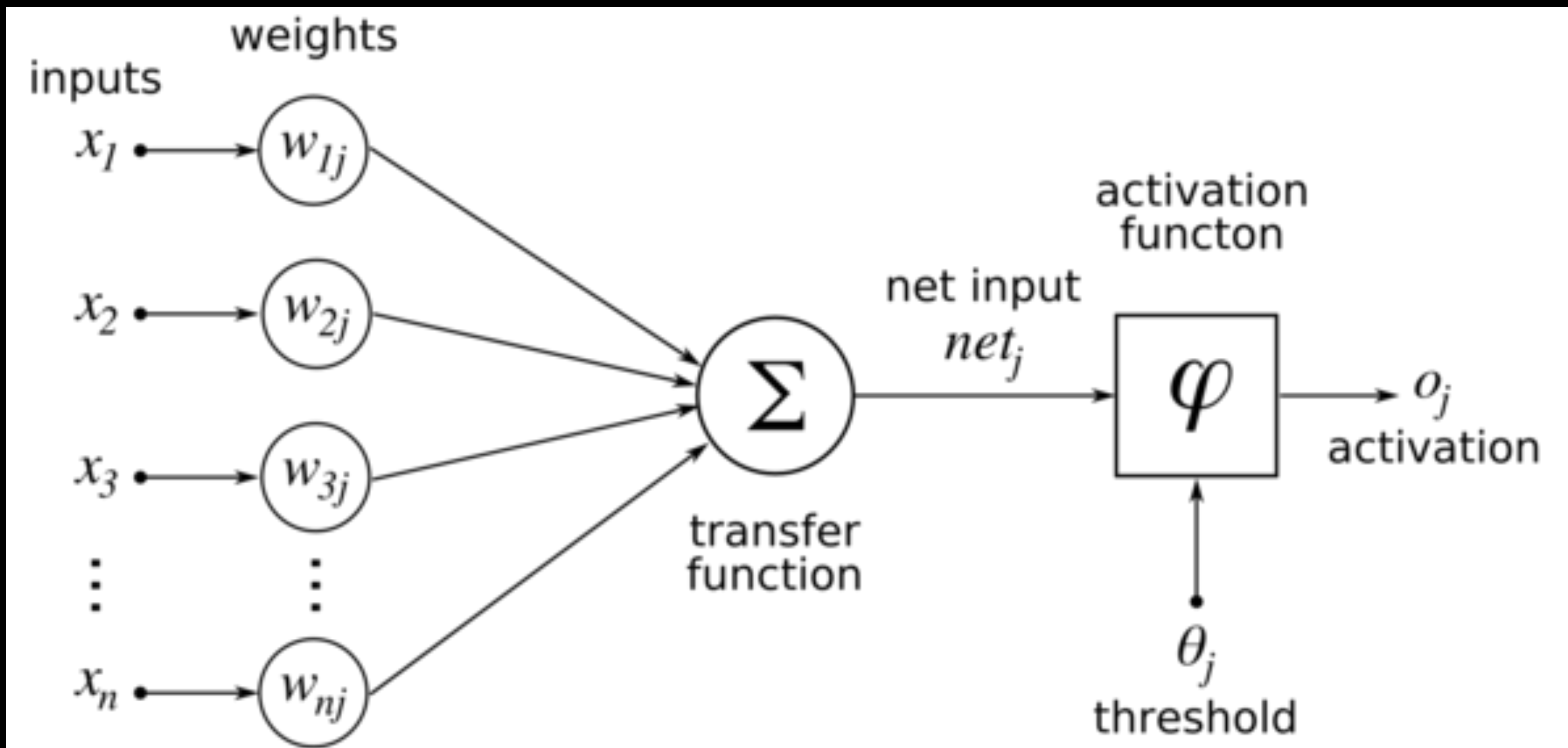
$$\text{Input} = a_1w_1 + a_2w_2 + a_3w_3 + \ldots + a_nw_n$$

$$\text{Input} = \sum_{i=1}^{n} a_iw_i$$

The Output

If Input > θ Output = 1

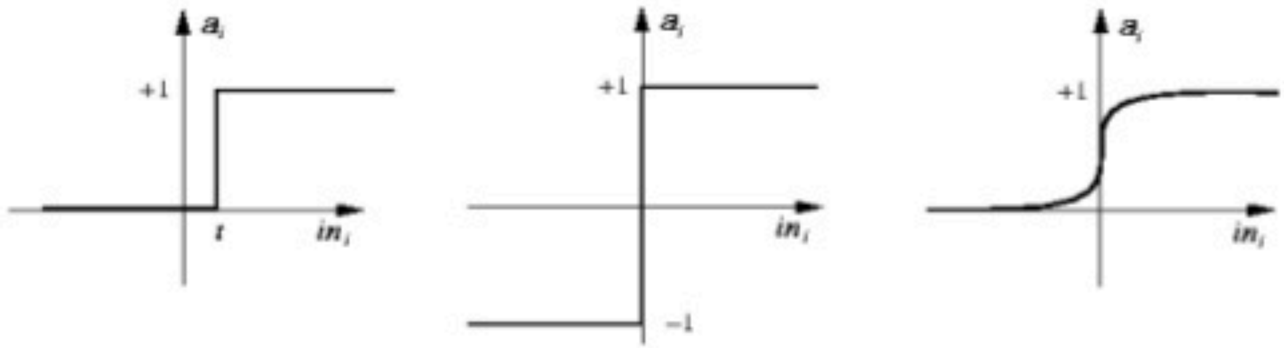
If Input < θ Output = 0



Why have an activation function?

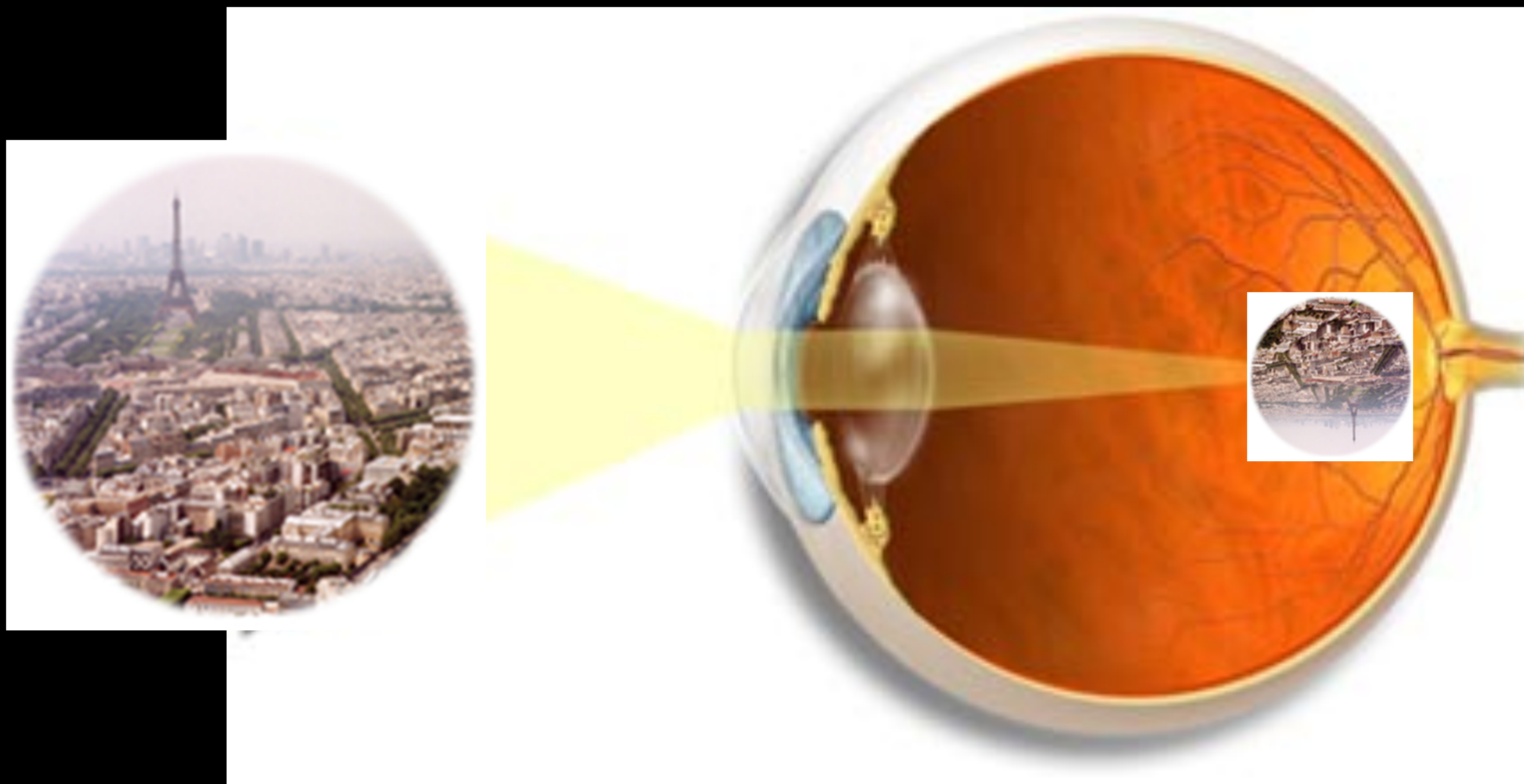
Hint: Can we simulate every neuron in the brain?

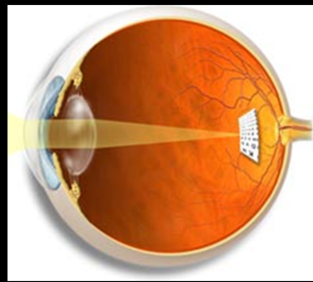
Activation Functions

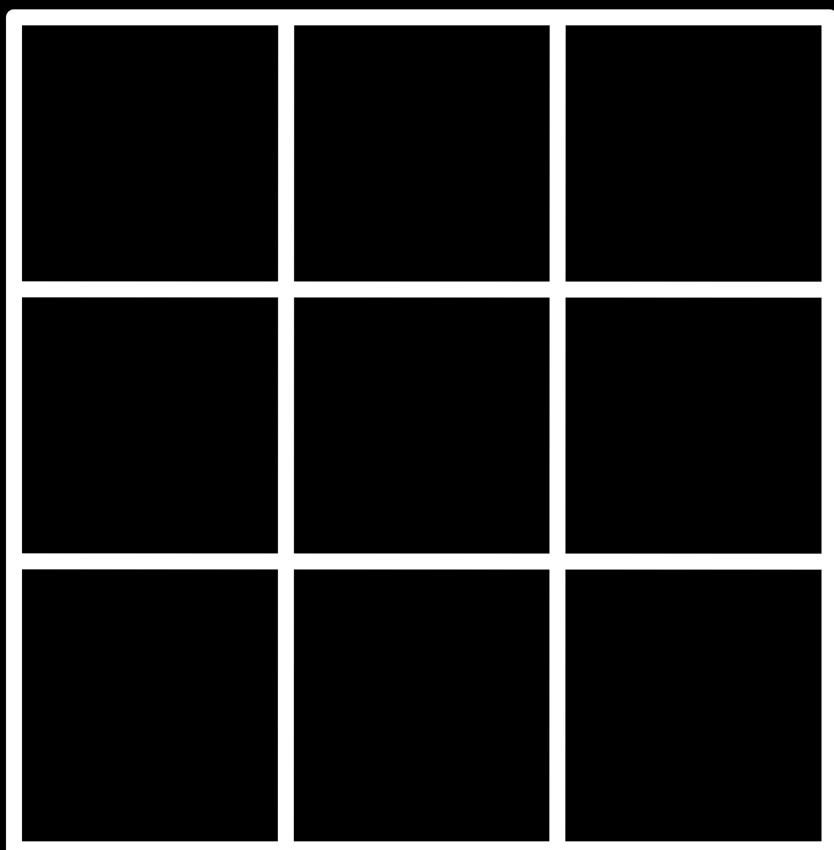


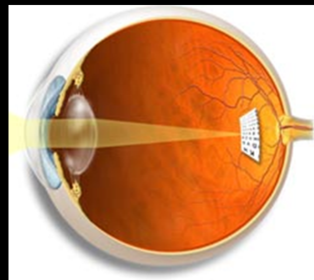
(a) Step function (b) Sign function (c) Sigmoid function

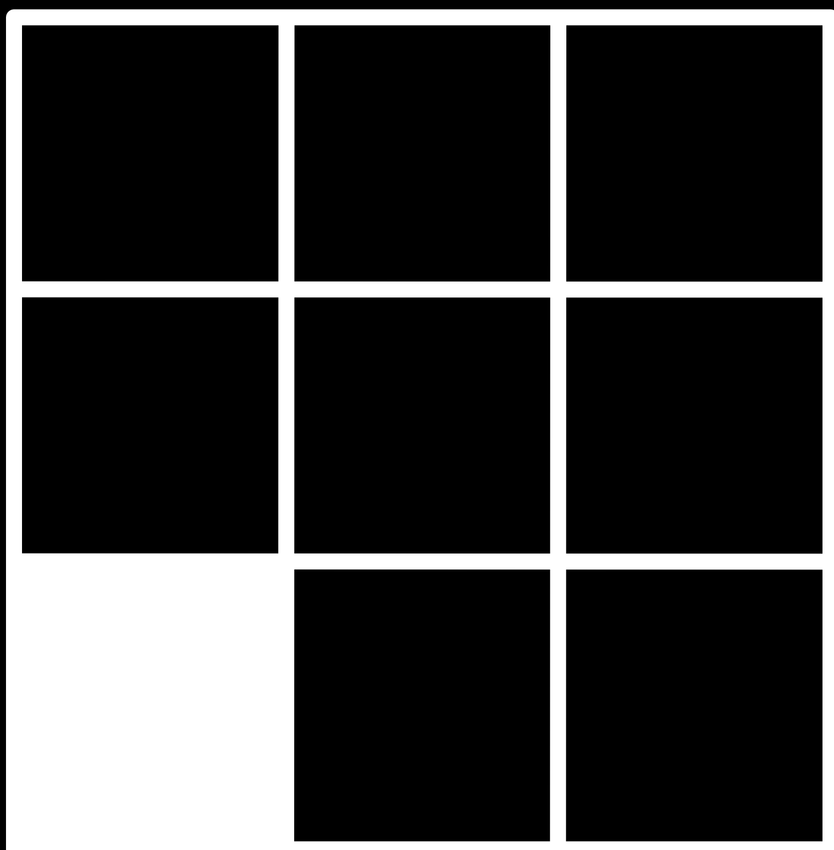
- $\text{Step}_t(x)$ = 1 if $x \geq t$, else 0 threshold=t
- Sign(x) = +1 if $x \geq 0$, else −1
- Sigmoid(x) = $1/(1+e^{-x})$

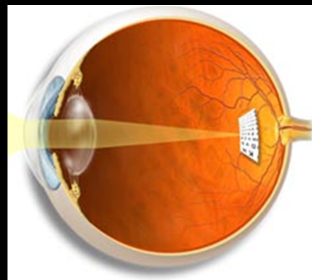


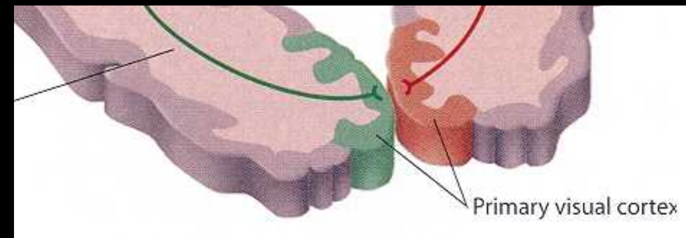


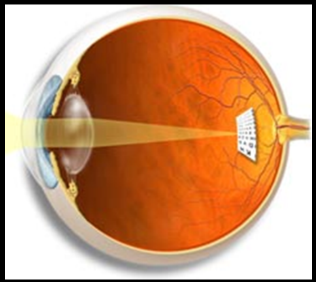


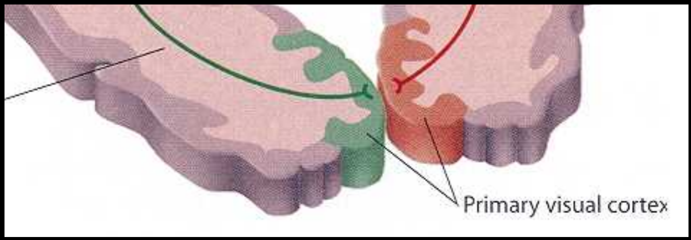


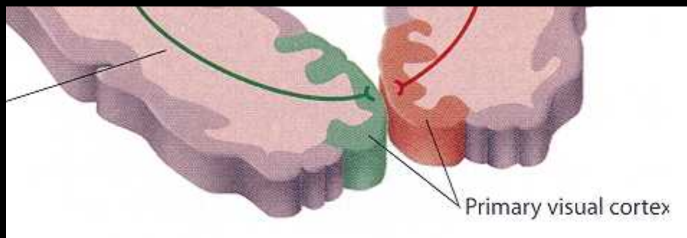


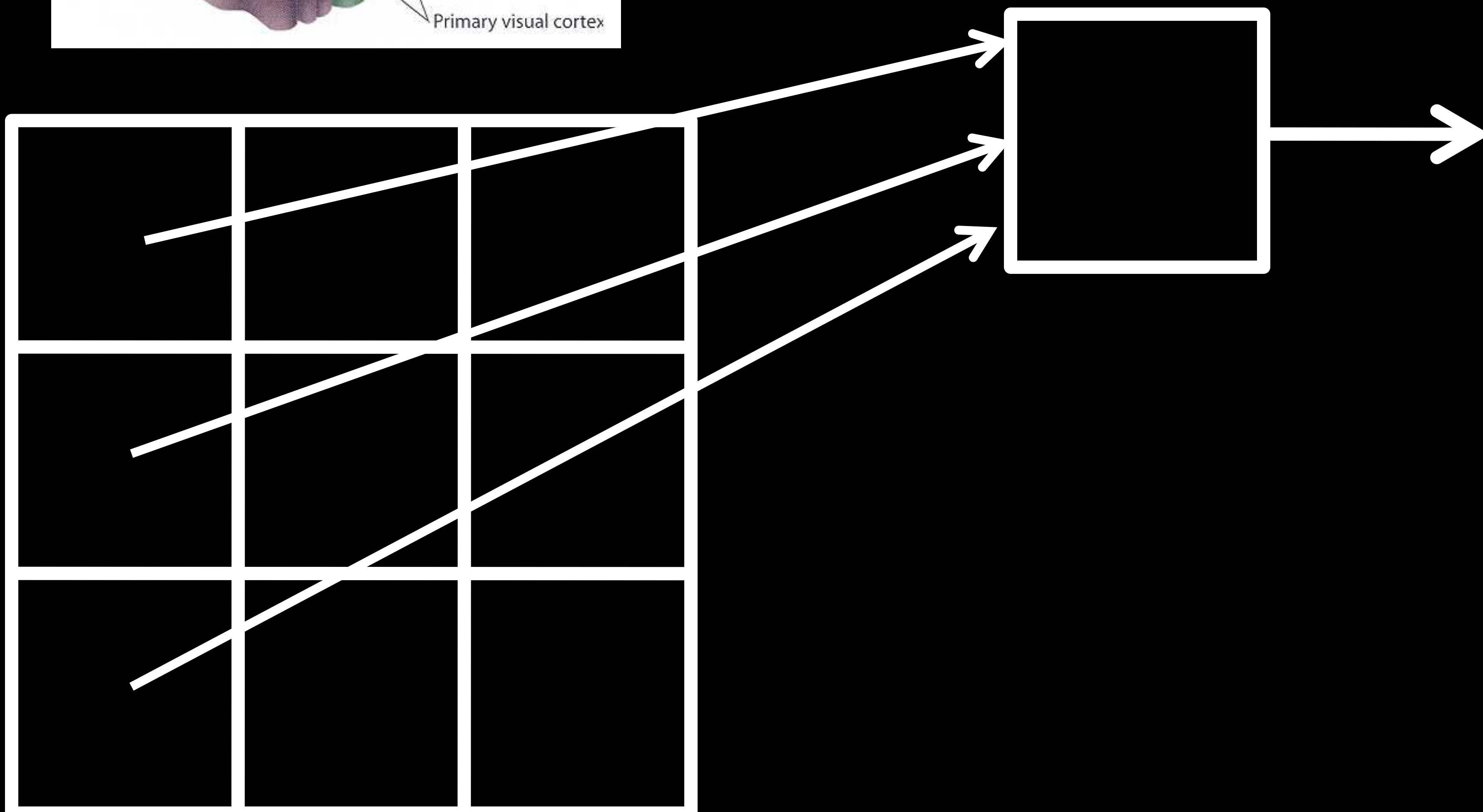


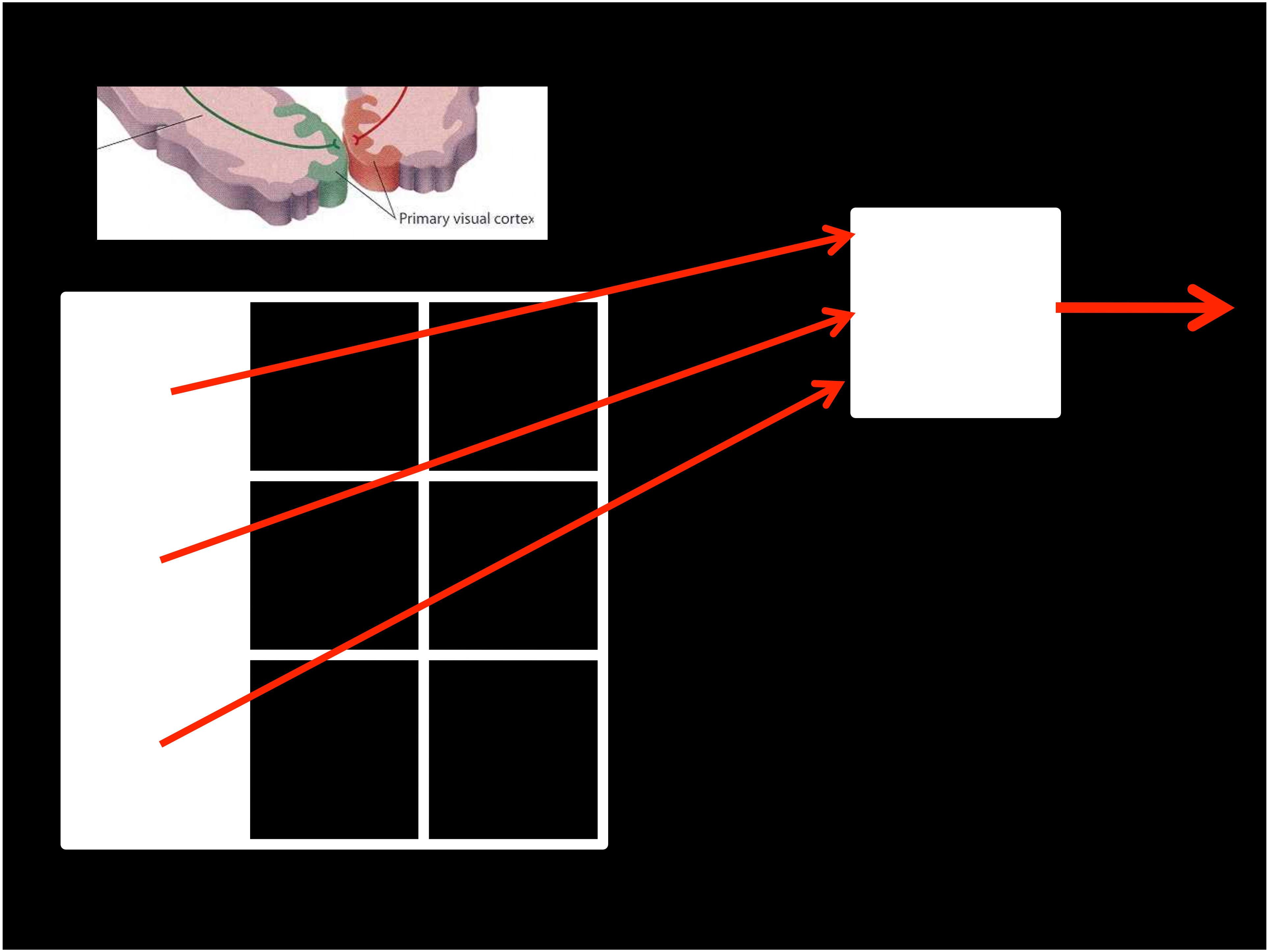

Primary visual cortex

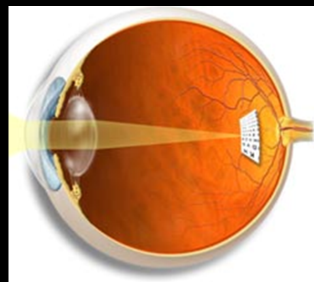


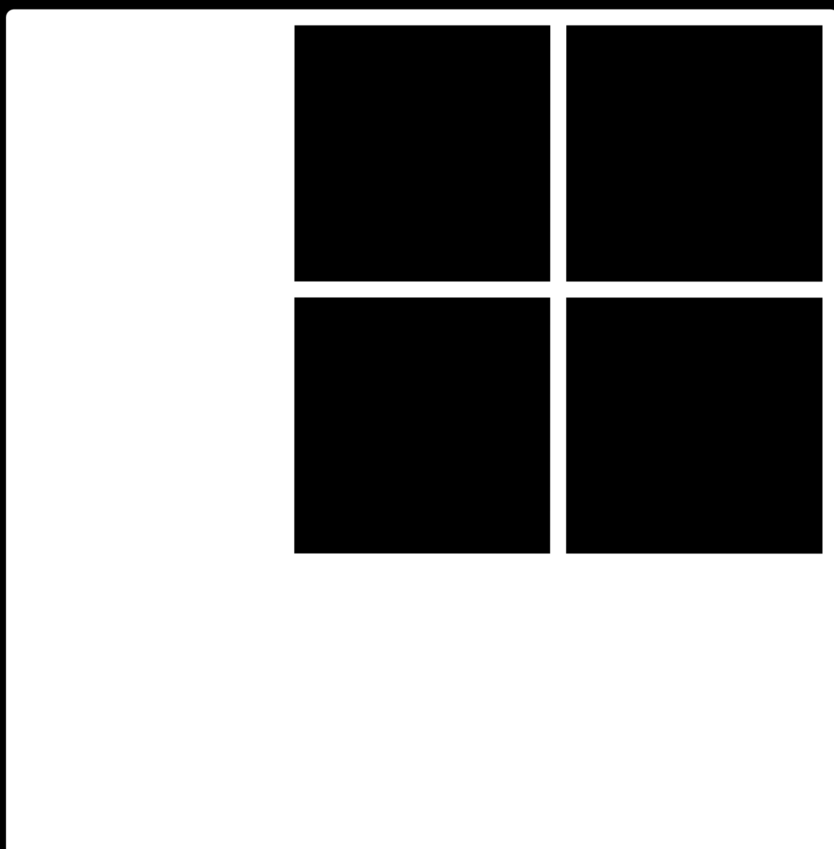

Primary visual cortex

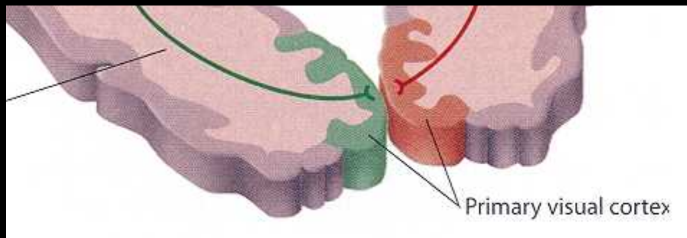

Primary visual cortex

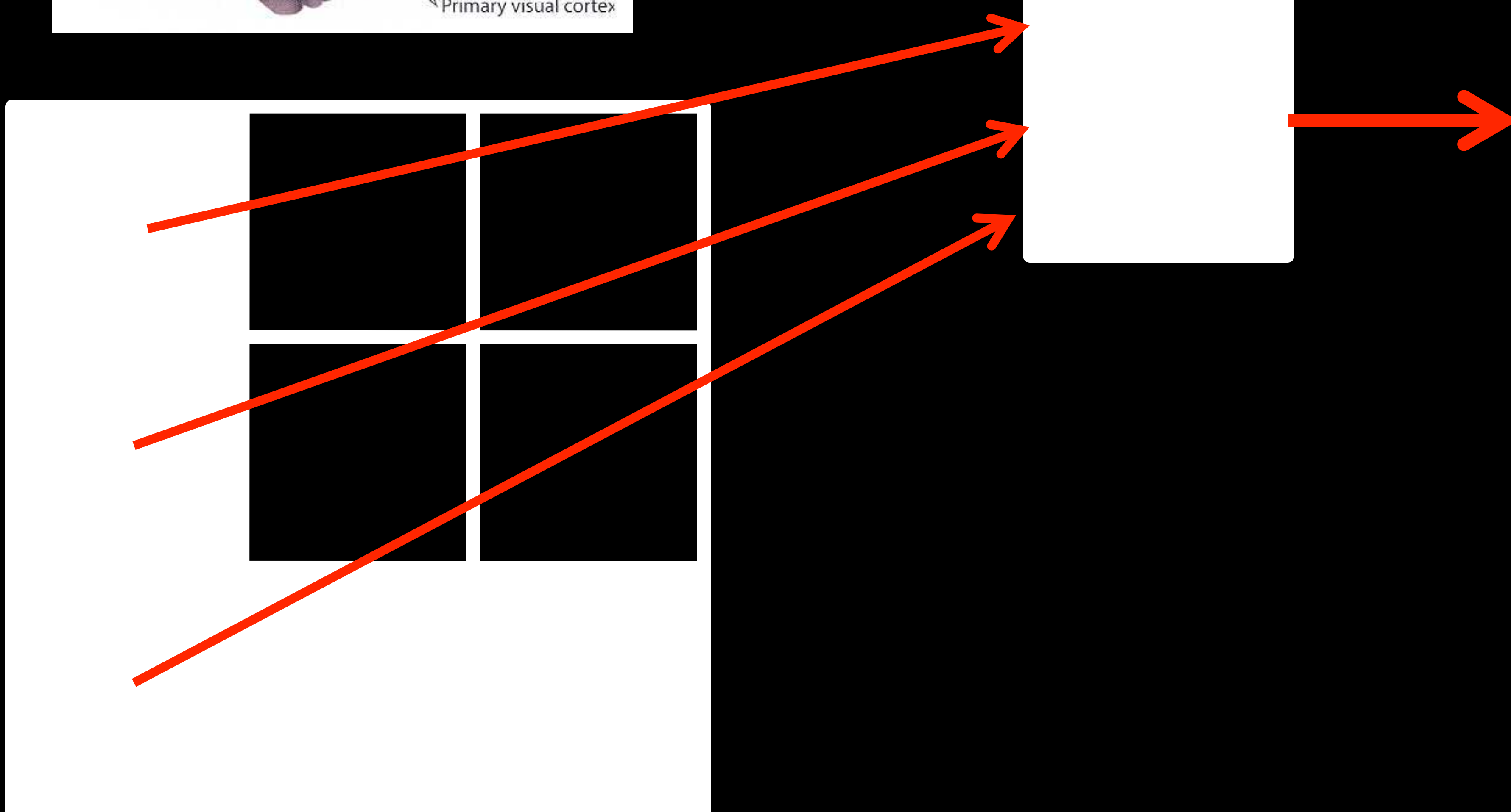


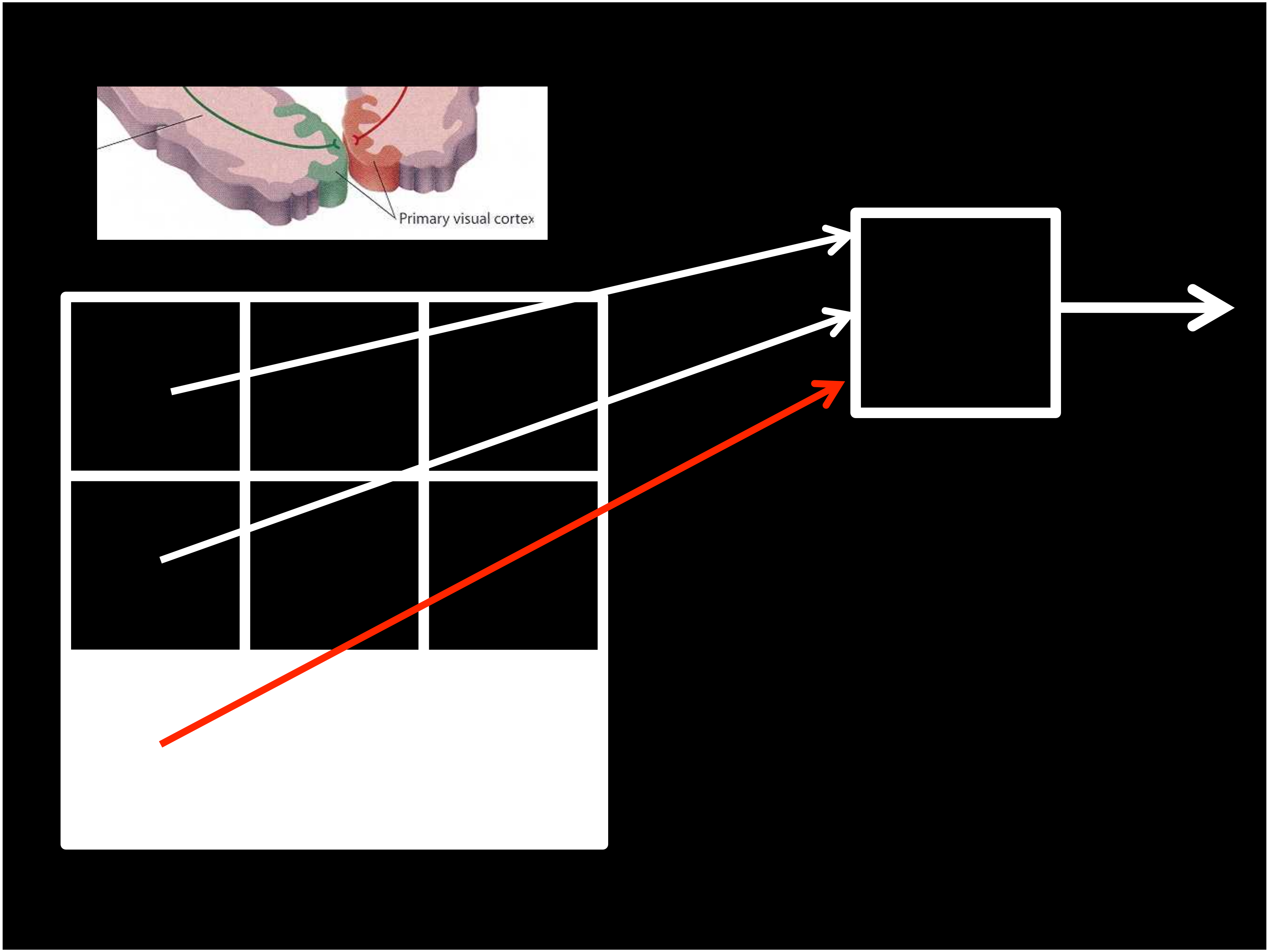

Primary visual cortex

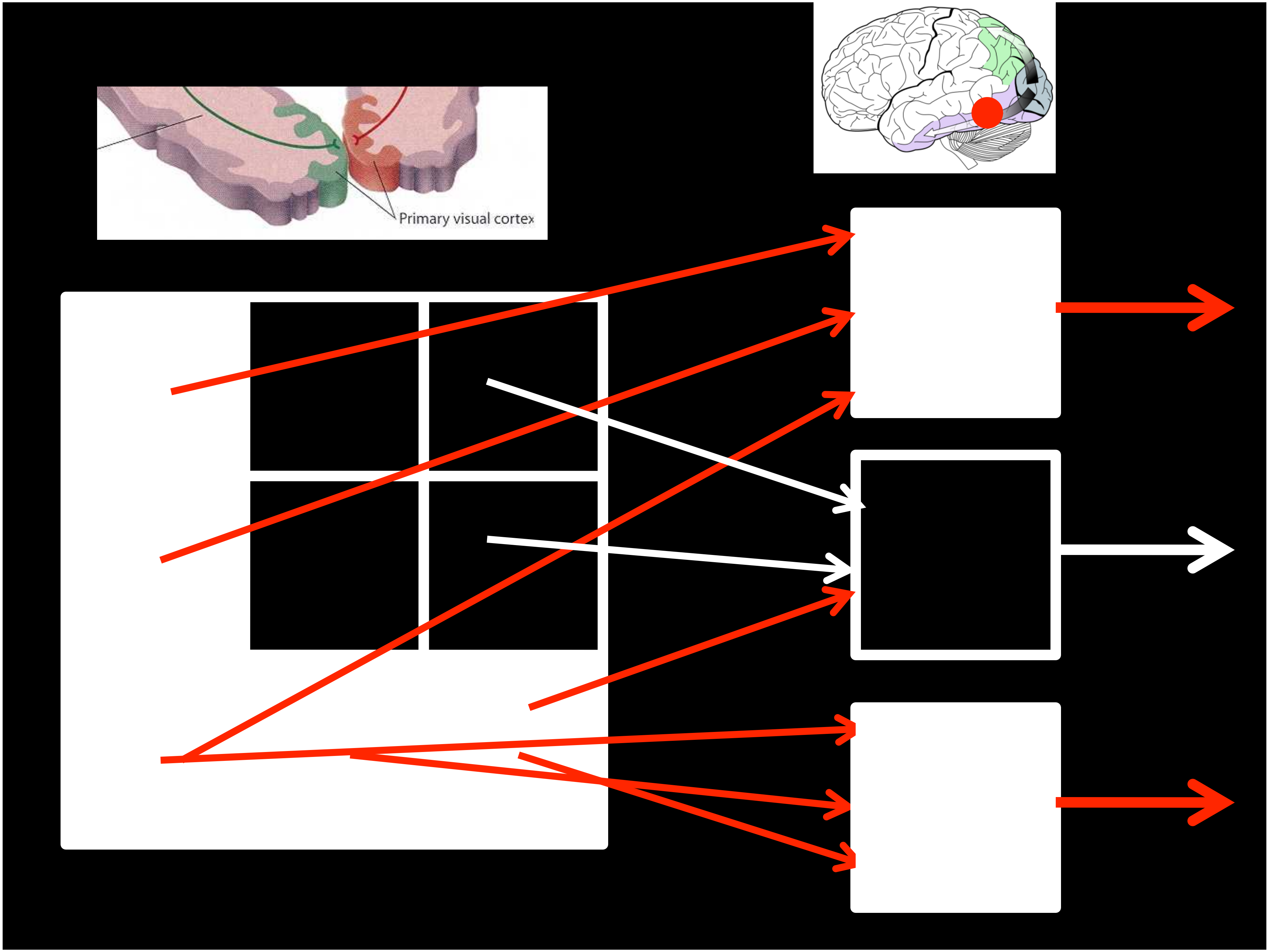


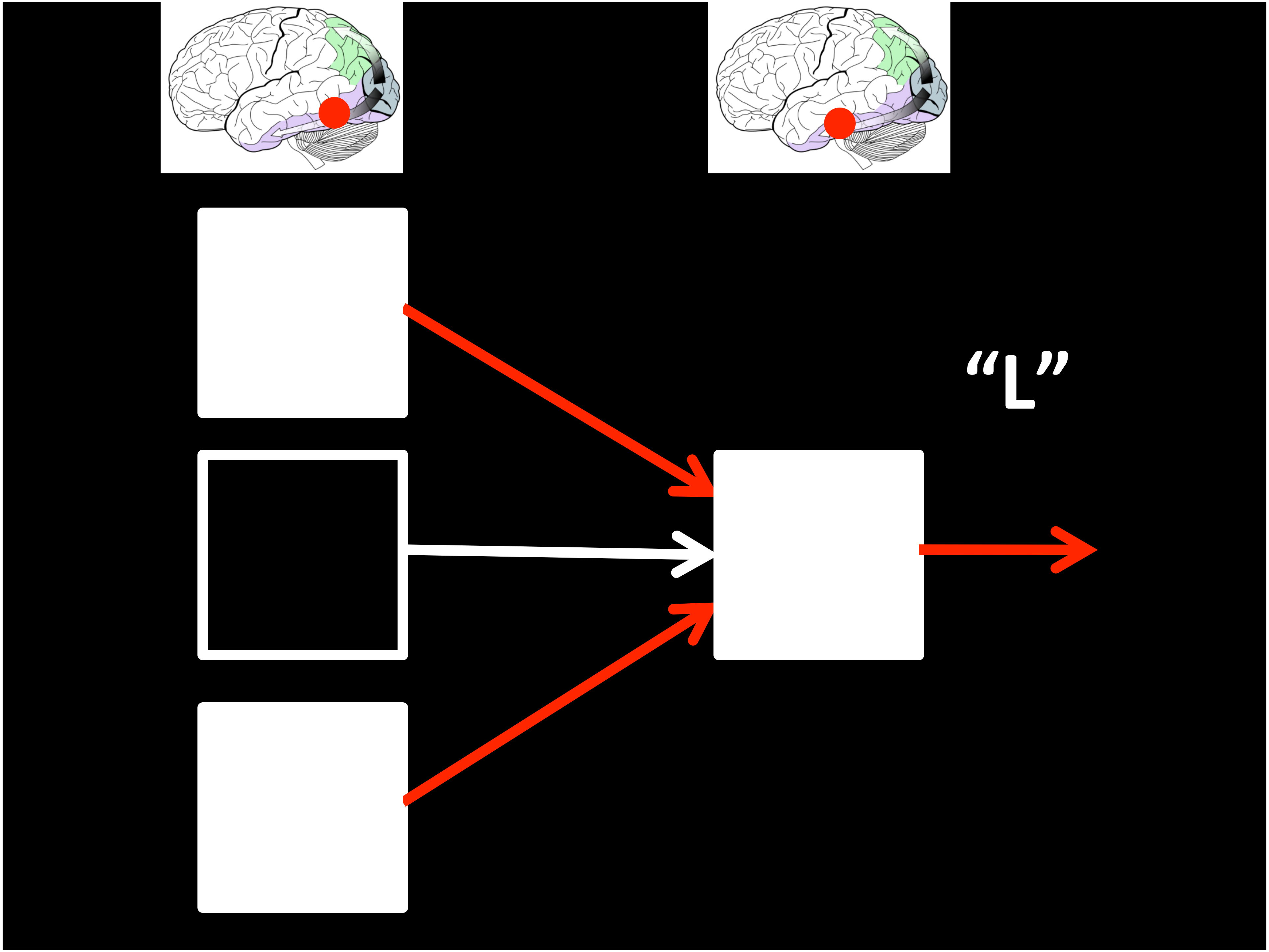


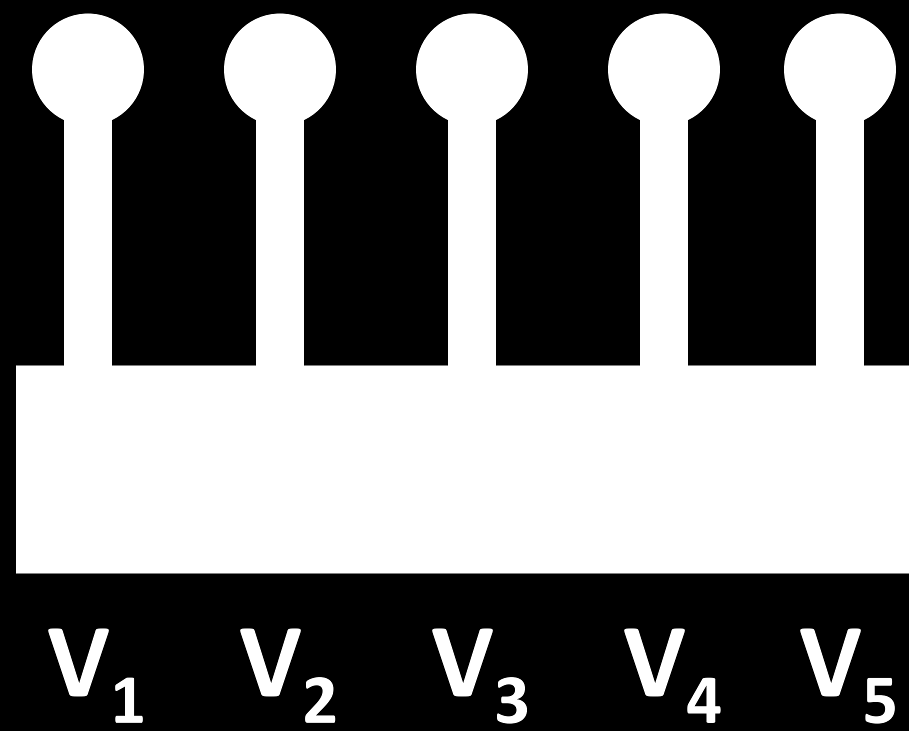

Primary visual cortex




Primary visual cortex


Primary visual cortex


"L"



Where: V_n = Output of a NN

Then it is easy…

1. Always choose the highest value option…
   (in TD gammon the best move…)

Tic Tac Toe

X	0.3	0.5
0.3	O	0.1
0.5	0.1	0.8

Then it is easy…

1. Always choose the highest value option…
   (in TD gammon the best move…)

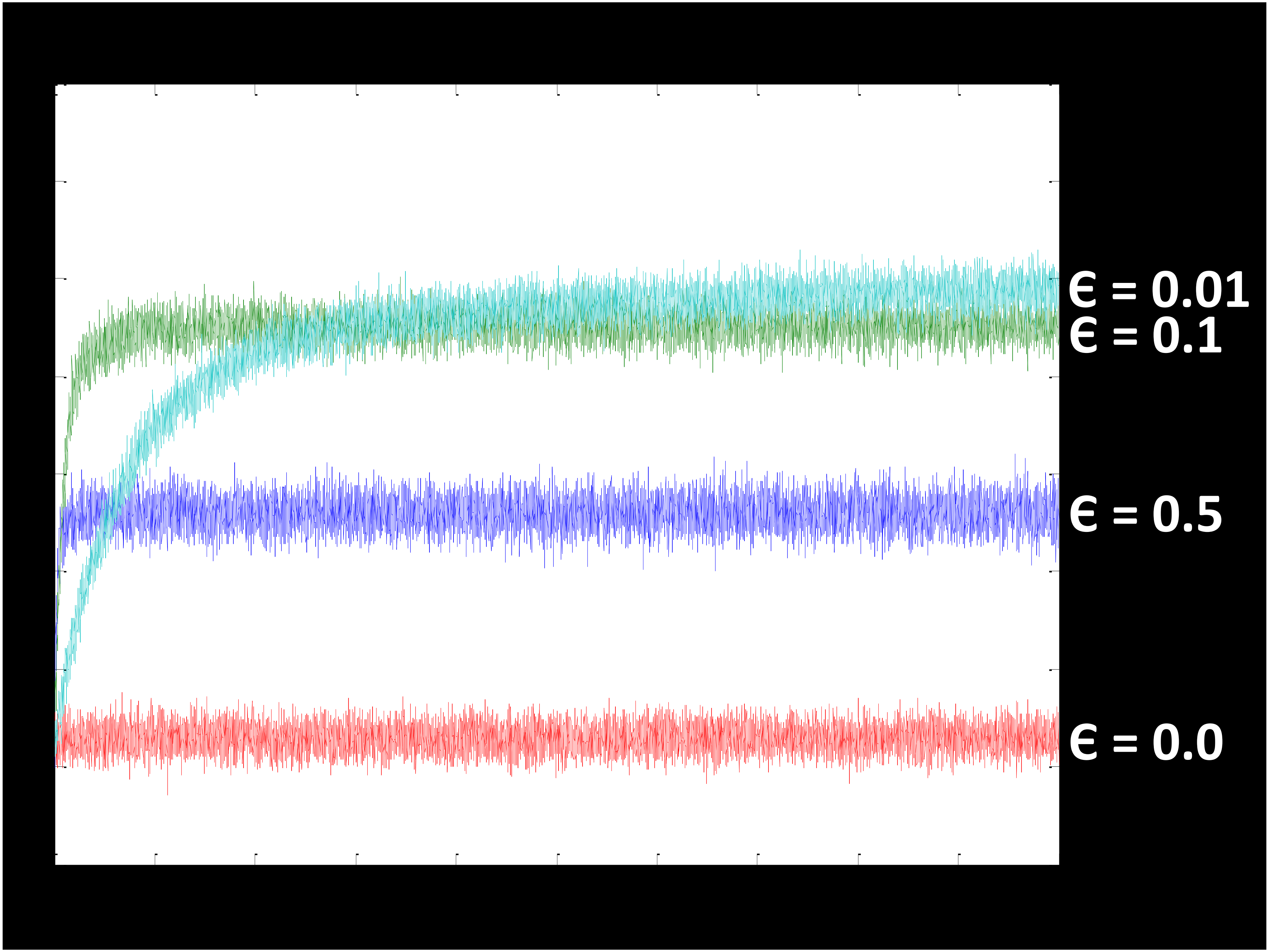
But why is this not always the best idea?

Then it is easy…

1. Always choose the highest value option…

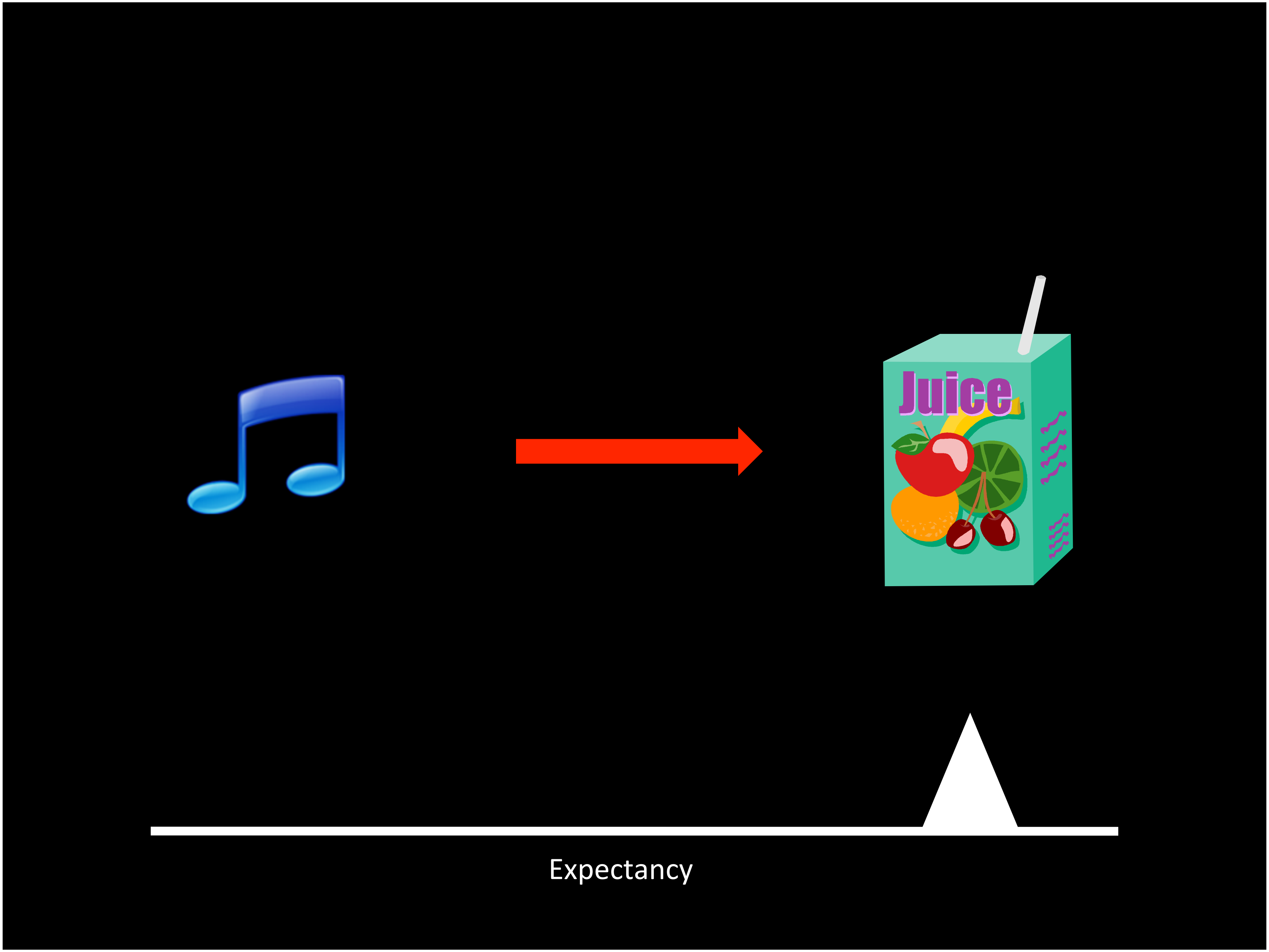
    (in TD gammon the best move…)

2. So, sometimes we need to EXPLORE as opposed to EXPLOIT



ϵ = 0.01
ϵ = 0.1
ϵ = 0.5
ϵ = 0.0

Learning


Juice
Expectancy

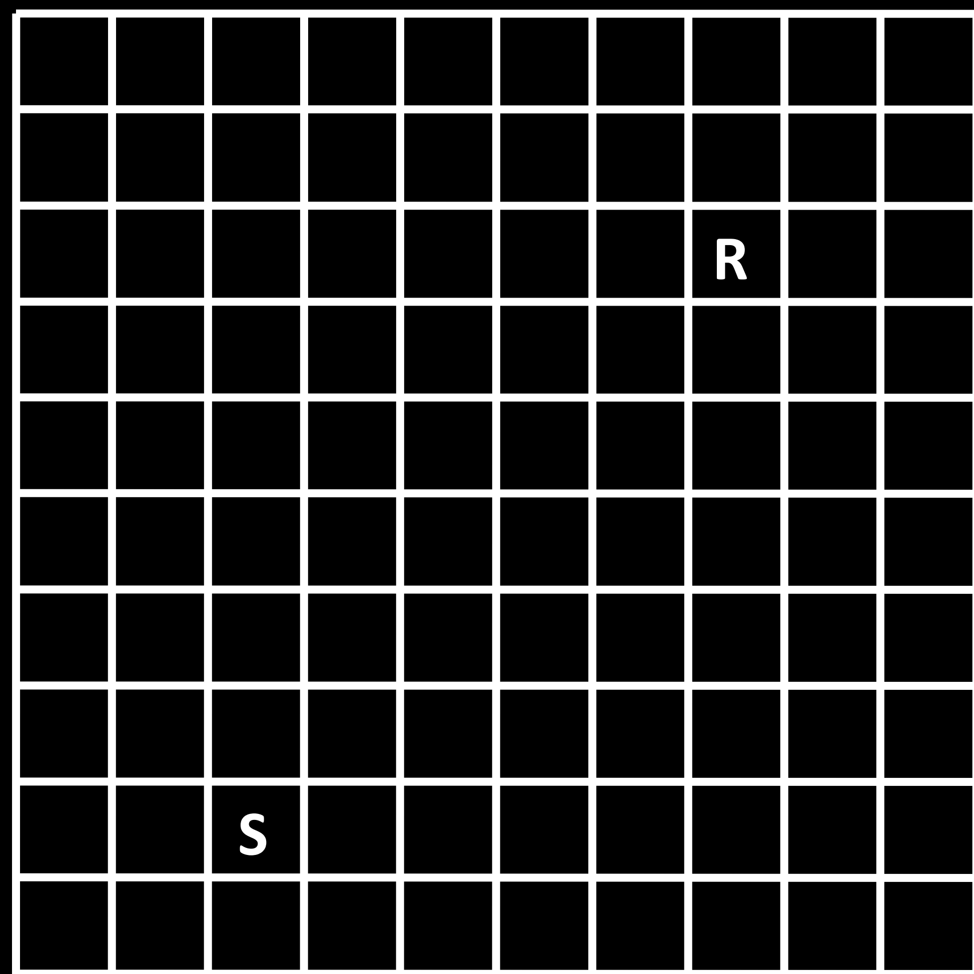
Rescorla – Wagner (1972)

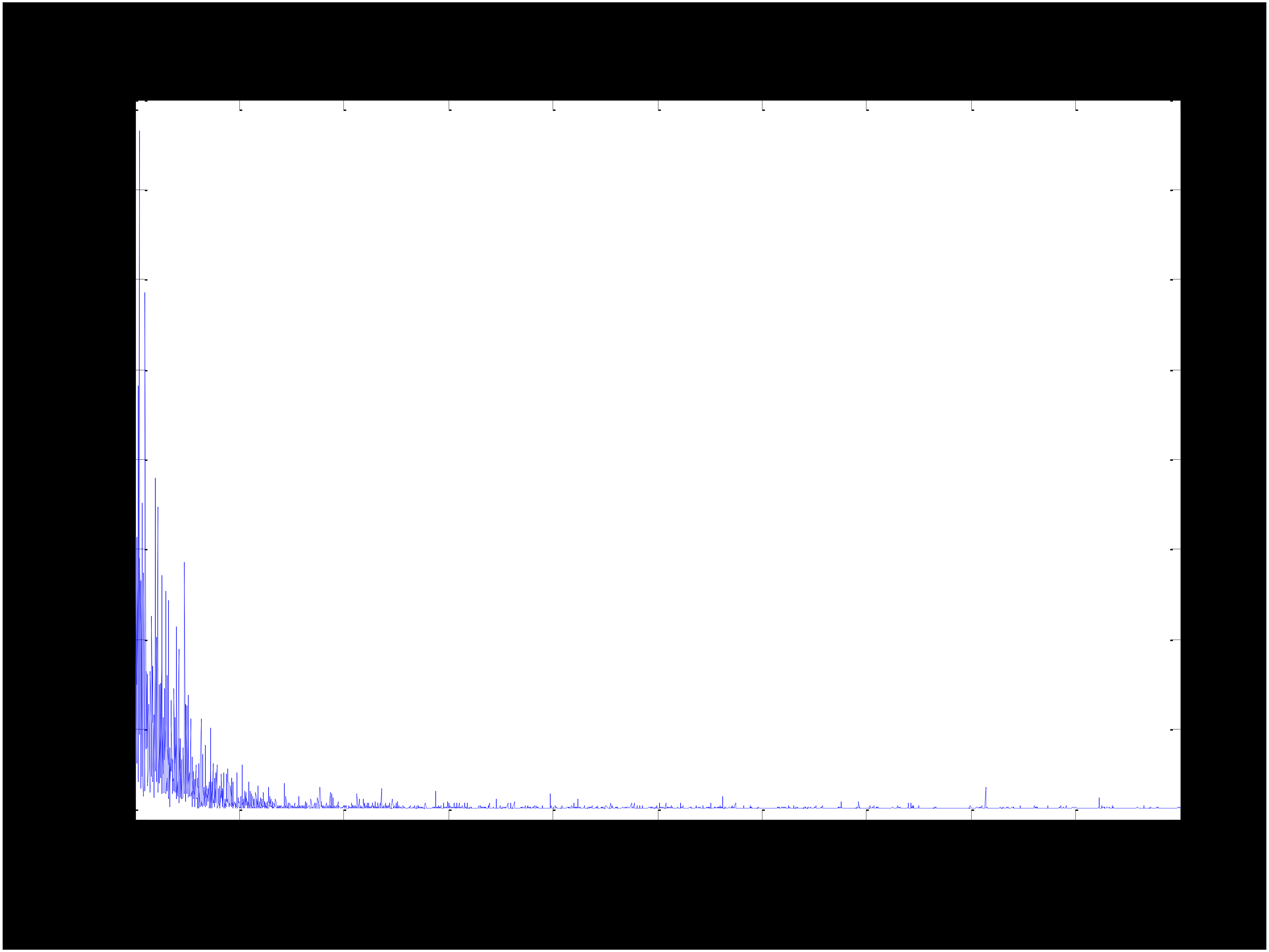
Prediction Error = Actual Value – Expected Value

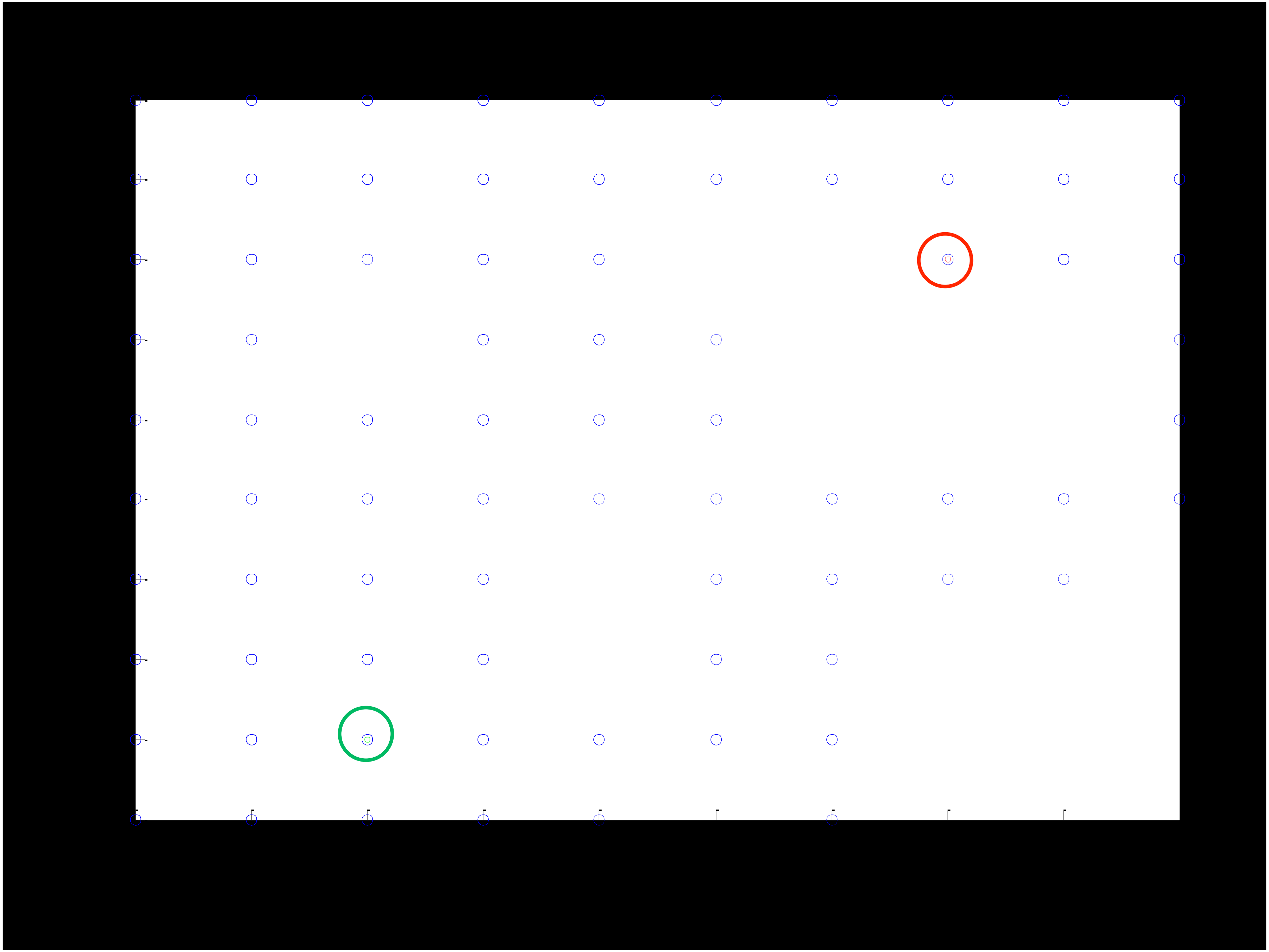
Rescorla – Wagner (1972)

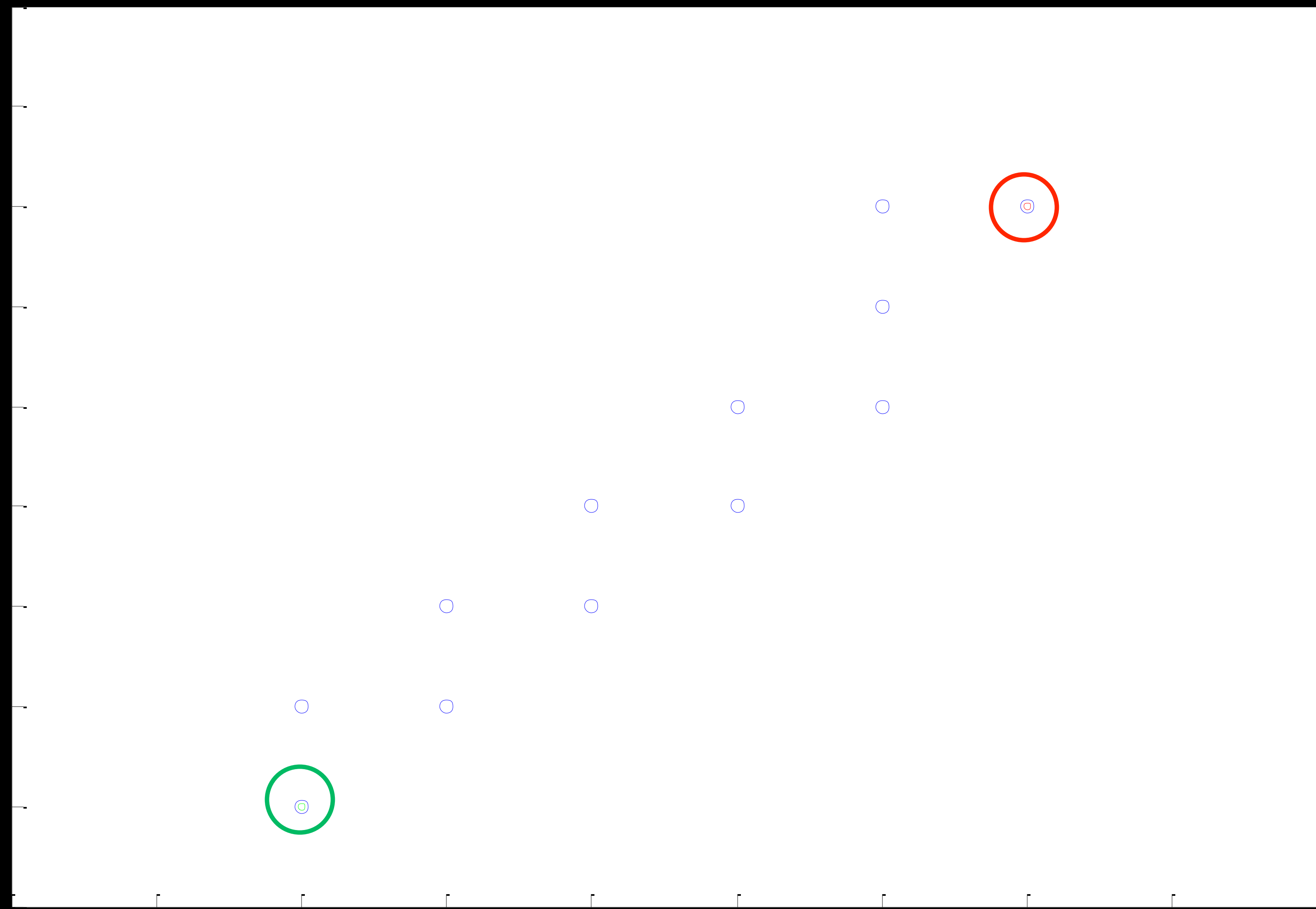
New Value = Old Value + PE

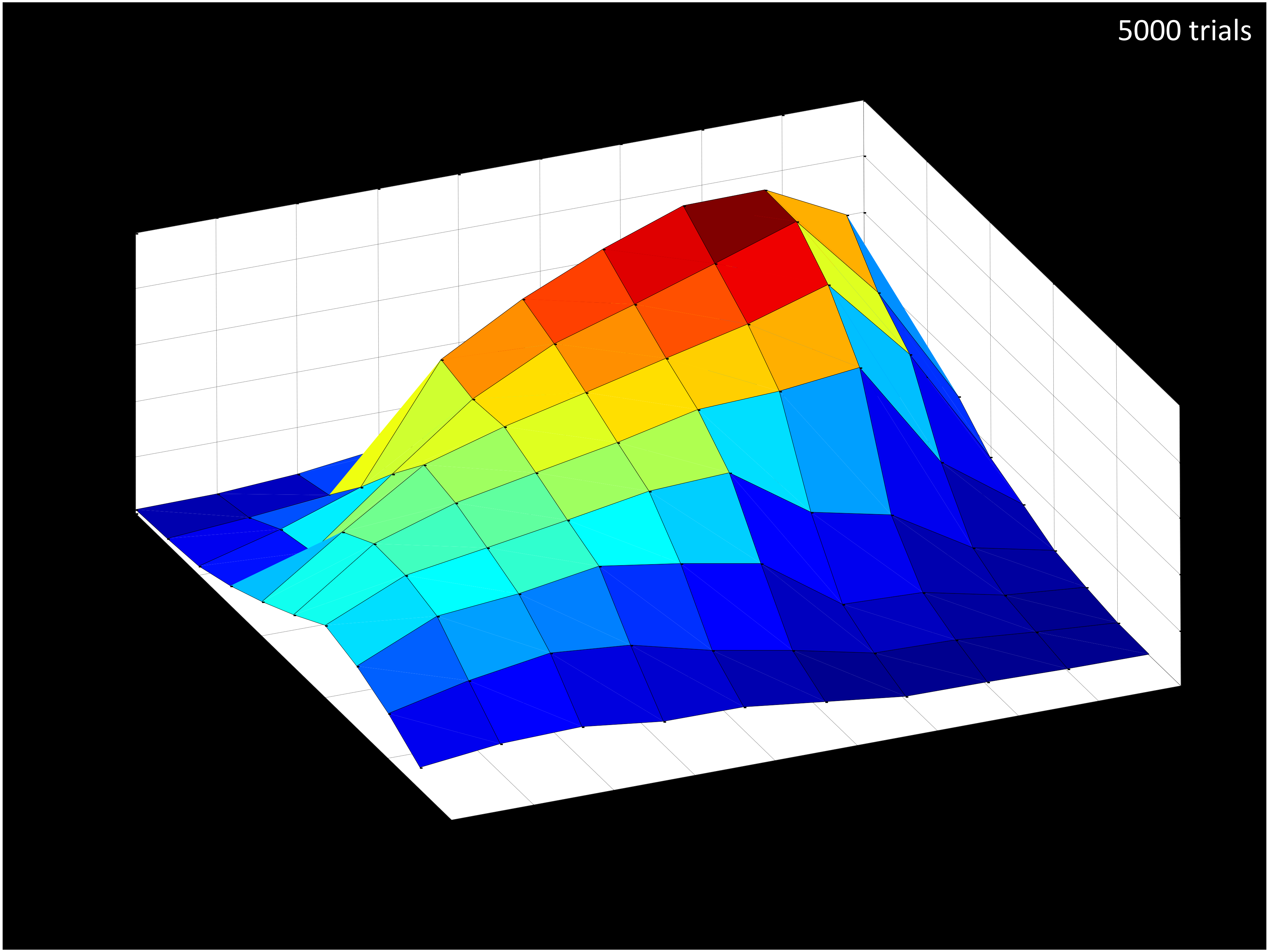
V_{tone} V_{reward}


R
S








5000 trials

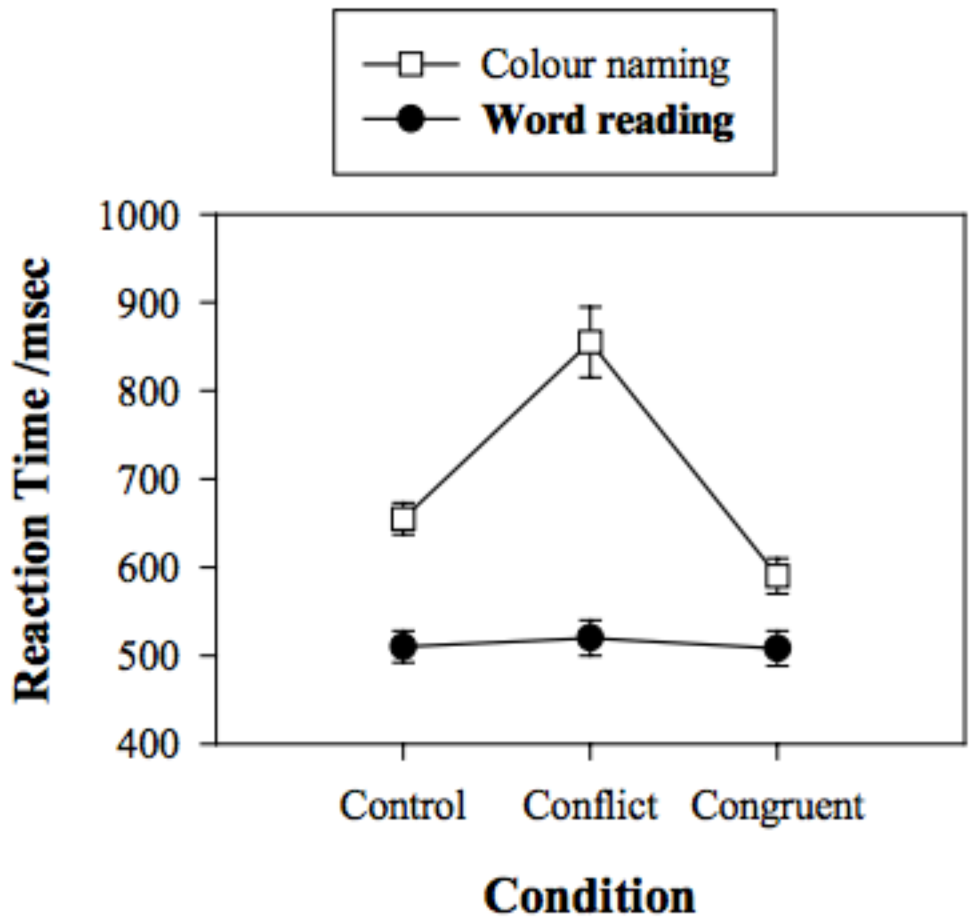


Figure 1: Reaction Times for all fundamental conditions in the Stroop task, after Dunbar & MacLeod (1984, p. 630). Standard error bars are shown.

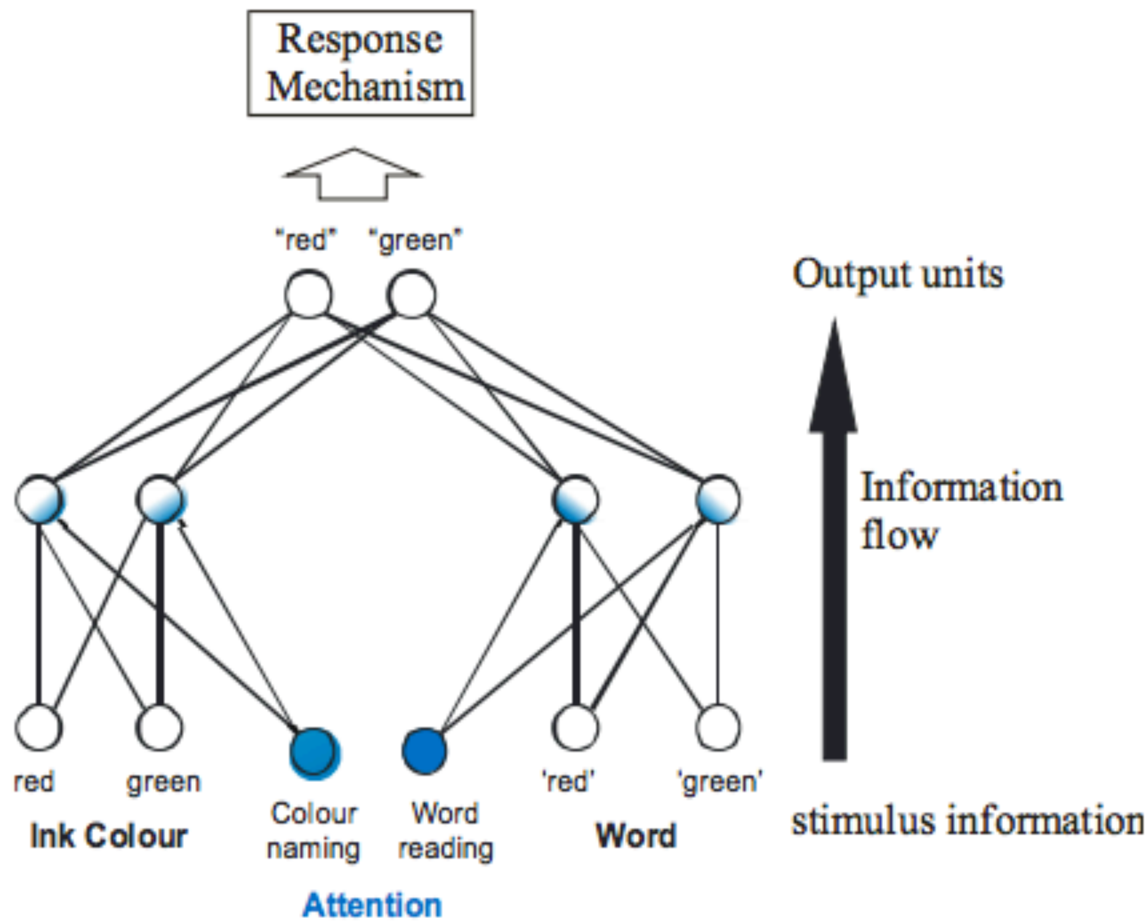


Figure 3: Architecture of the Cohen model, after Cohen et al (1990, figure 3, p. 339). The sites and sources of attentional modulation are shown shaded.

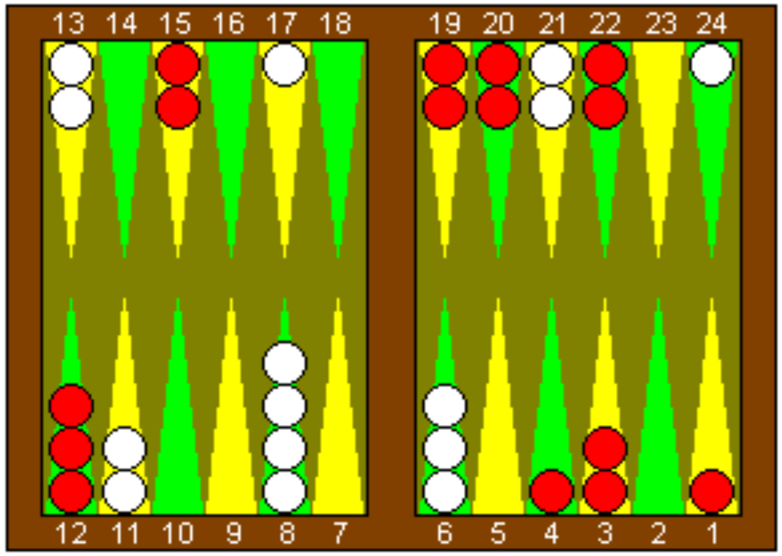
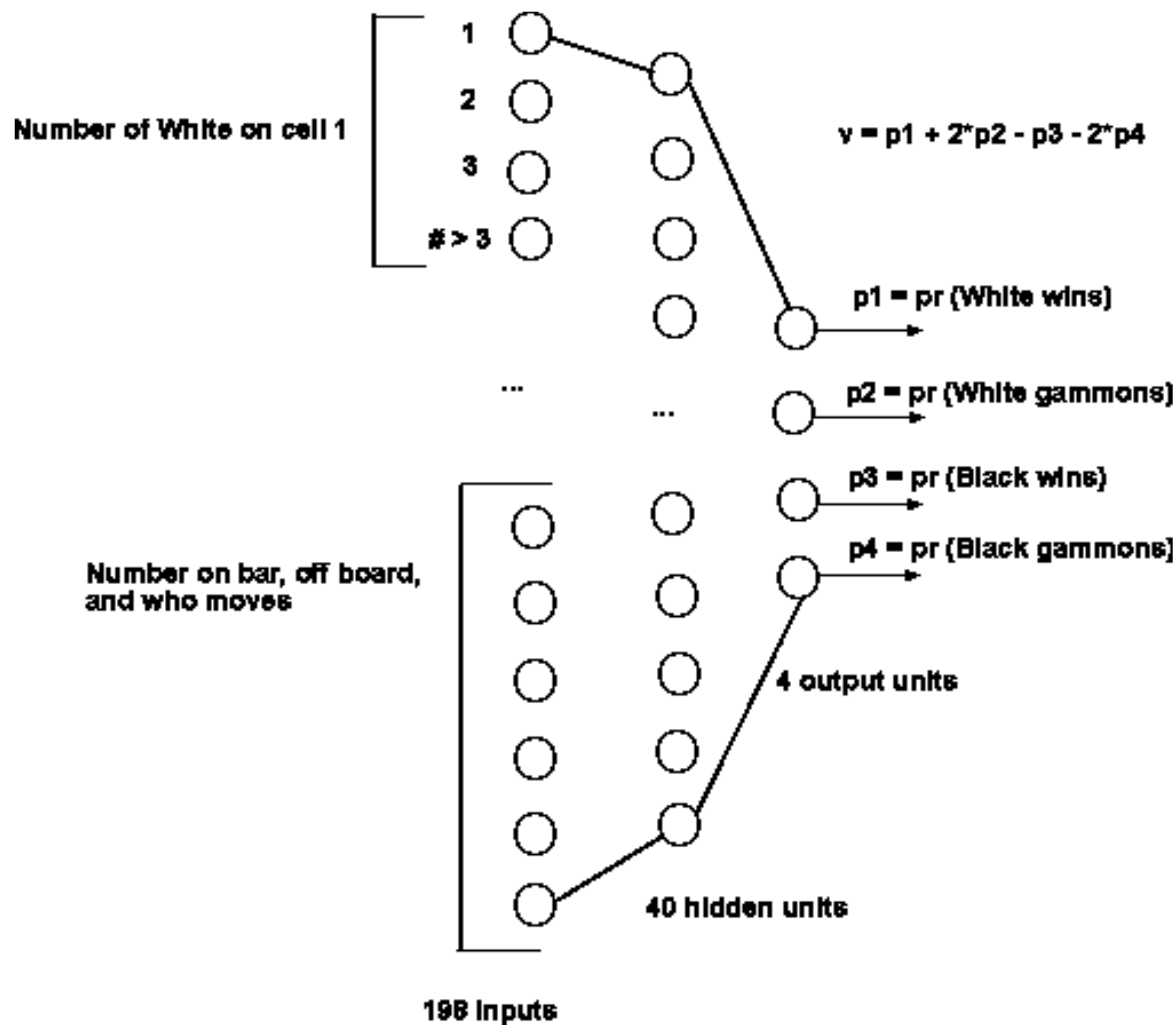


Figure 3. A complex situation where TD-Gammon's positional judgment is apparently superior to traditional expert thinking. White is to play 4-4. The obvious human play is 8-4*, 8-4, 11-7, 11-7. (The asterisk denotes that an opponent checker has been hit.) However, TD-Gammon's choice is the surprising 8-4*, 8-4, 21-17, 21-17! TD-Gammon's analysis of the two plays is given in Table 3.


Number of White on cell 1
1
2
3
# > 3
v = p1 + 2*p2 - p3 - 2*p4
p1 = pr (White wins)
p2 = pr (White gammons)
p3 = pr (Black wins)
p4 = pr (Black gammons)
Number on bar, off board, and who moves
4 output units
40 hidden units
198 inputs