Neurorobotics

Module 2: Neurorobot Design Principles

Lecture 6: Design Principle 3 Case Study – Anxious and Curious Behavior in a Neurorobot

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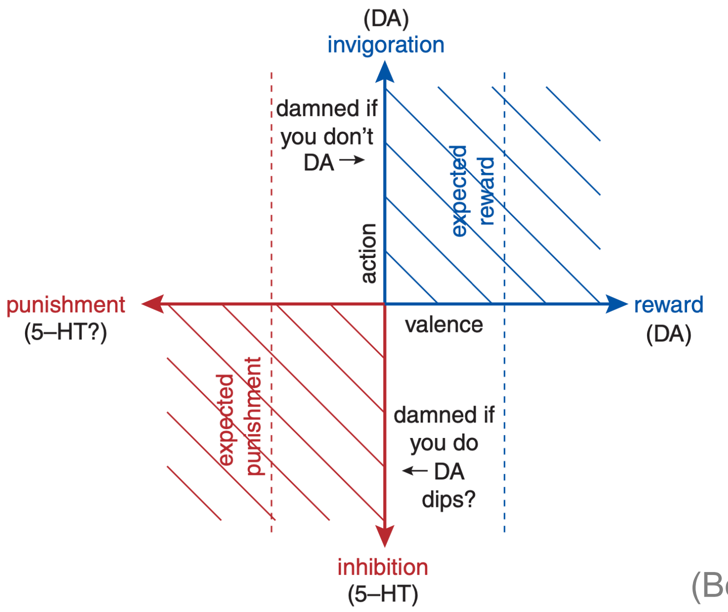
Prologue

There is a behavioral tradeoff between invigorated and inhibited activity

This tradeoff may be governed by dopamine and serotonin



(Boureau and Dayan, 2011)

TransAIR Workshop on Cognitive Architectures for Robot Agents

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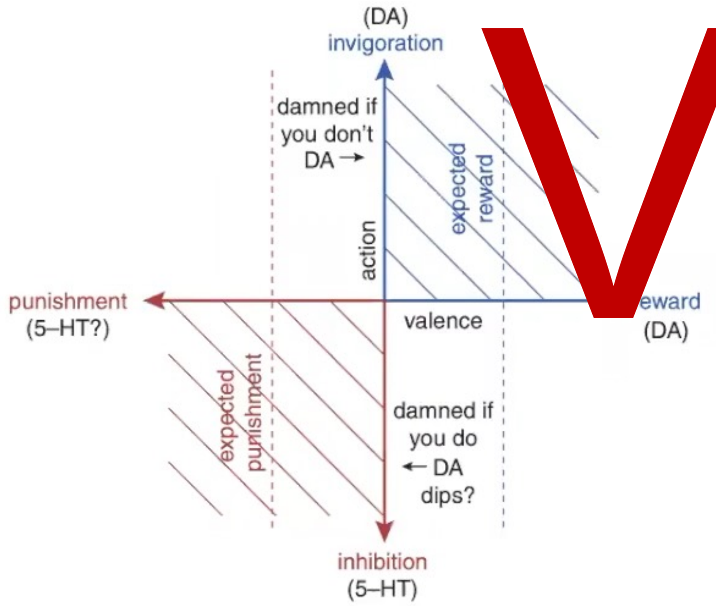
Behavioral Tradeoff between:

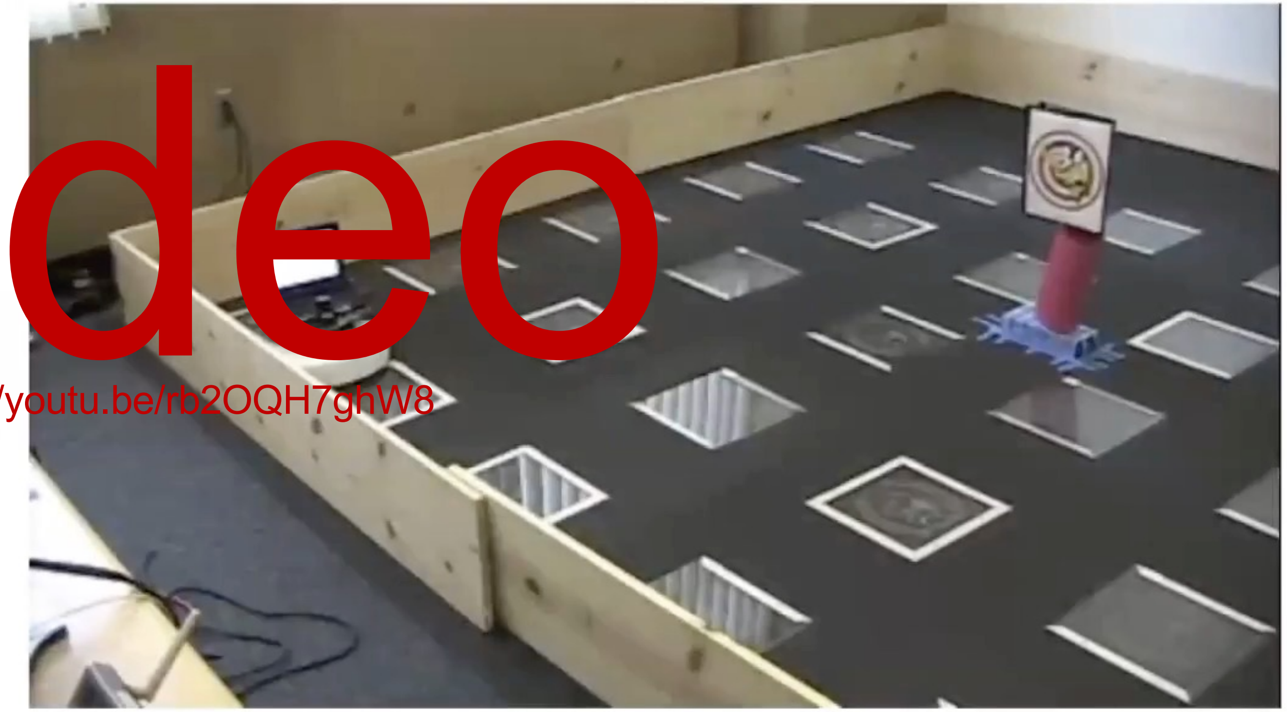
- Invigorated and Withdrawn
- Risk taking and Risk Averse
- Exploration and Exploitation



From Boureau and Dayan, 2011

Video

https://youtu.be/rb2OQH7ghW8



Krichmar, J. L. (2013). "A neurorobotic platform to test the influence of neuromodulatory signaling on anxious and curious behavior." Frontiers in Neurorobotics **7**.

Prologue

Acetylcholine and noradrenaline can direct attentional resources

Prologue

The frontal cortex can influence cognitive control

- Gating on and off behaviors
- Influencing neuromodulatory levels
  - The orbitofrontal cortex (OFC) has strong interactions with the dopaminergic system
  - The medial prefrontal cortex (mPFC) has strong interactions with the serotonergic system

The Case Study

Demonstrate that putting these ideas together can lead to interesting, natural behavior in a robot

Focus:

- Interaction between neuromodulators and the frontal cortex
- Implemented in a neural network
- That controls an iRobot Create Roomba robot

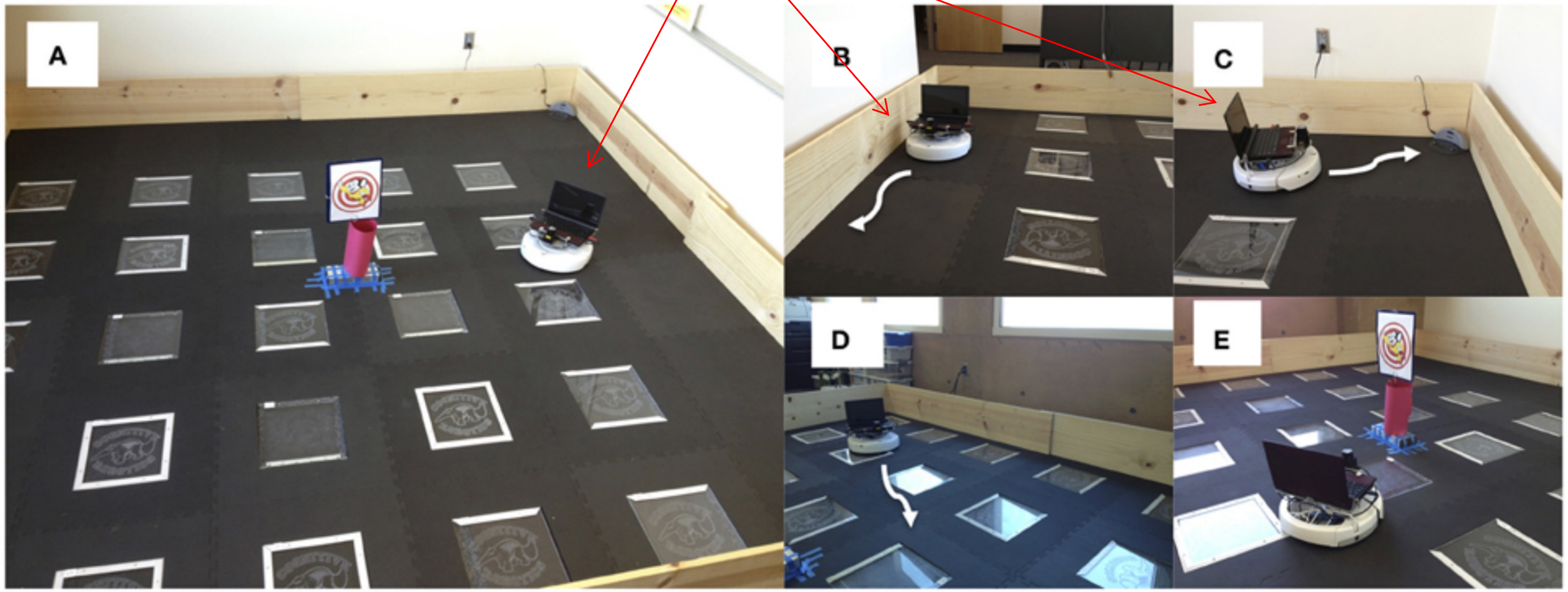
The Case Study

Mimic a rodent open-field experiment

- When placed in a new environment
  - Rodents typically stay near their nest or
  - Follow closely along the walls of an environment
- As they become more comfortable in the environment
  - They will venture out into the open area of the arena
  - Explore novel objects placed in the arena.

The neural network runs on a laptop mounted on the robot
Touch sensors are used to detect bumps
Webcam monitors light levels
Laser range finder detects objects

iRobot Create
Roomba robot



The Case Study

Goal of the study

- Test how dopaminergic and serotonergic neuromodulation influence the ability to cope with a stressful event
- Each experimental trial lasted 240 seconds
- Experiments were conducted in the dark.
- Halfway through the trial, the lights were flashed on and then off.
- This mimics a stressful event in the open-field test
  - Rodents typically prefer the dark

Robot Control

Robot control is achieved through processing events and states

- States are behavioral primitives
- Events were driven by sensory signals
- An event can cause a switching of behavior states

The neural simulation

- Arbitrates between incoming events
- Decides when to switch states

Robot Control

A simulation cycle occurs approximately once per second, i.e., the time needed to

- Read the robot's sensors
- Update the neural simulation
- Send a motor command

Robot Control

Three sensory events

1. Object Detected
   - Triggered when the laser range finder detects an object
     - Between 12 and 30 degrees wide
     - Closer than one meter
2. Light Detected
   - Triggered when the average pixel brightness in the grayscale image > 50%
3. Bump Detected
   - Triggered by the robot's bump sensors
   - Triggered when the laser detects an object closer than 20 cm

Robot Control

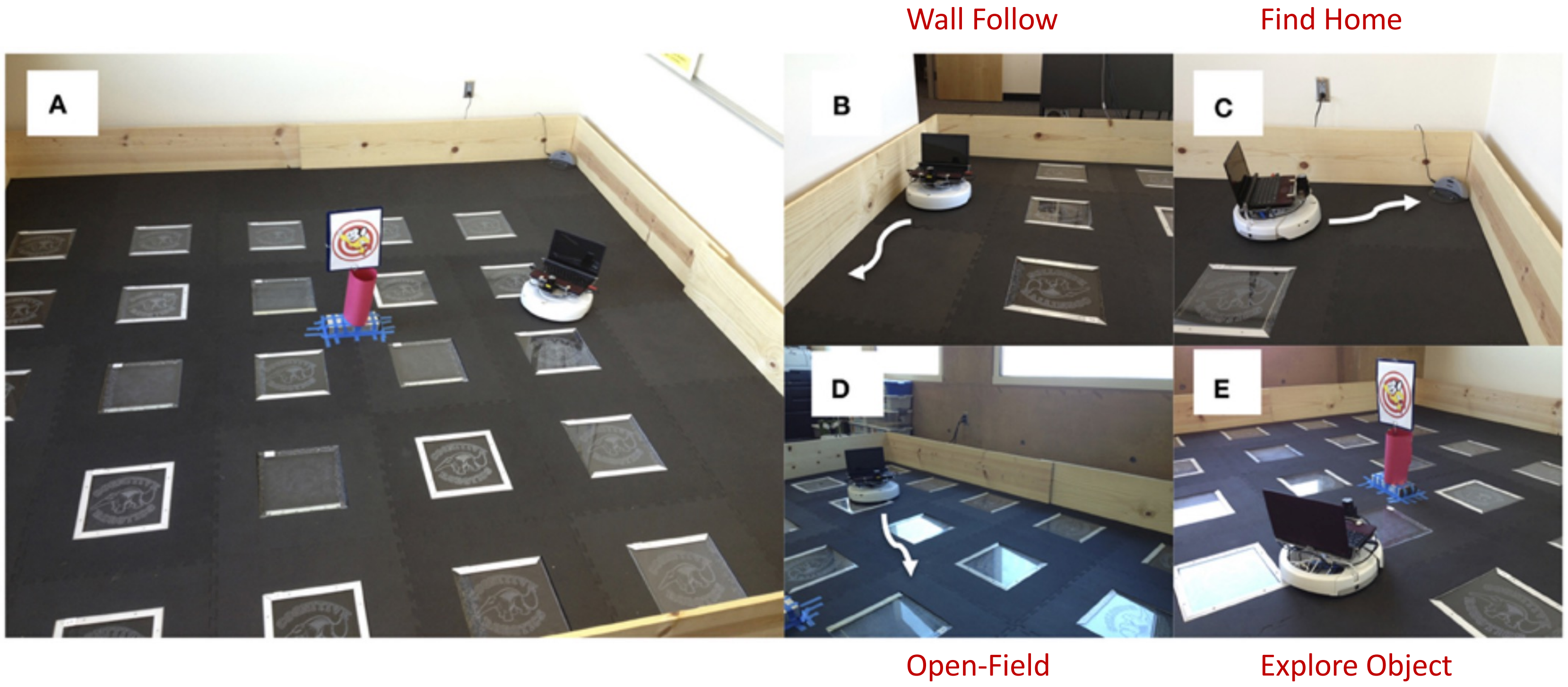
Four behavior states

1. Wall Follow
   - Robot follows the wall to its right

2. Find Home
   - Robot moves in a random pattern until it detects the Roomba docking station via an IR beam (range of ~ 500 cm)

3. Open-Field
   - Robot drives toward the most open area of the environment, based on laser range finder data

4. Explore Object
   - Robot moves toward the object detected by the laser



Wall Follow
Find Home
A
B
C
D
E
Open-Field
Explore Object

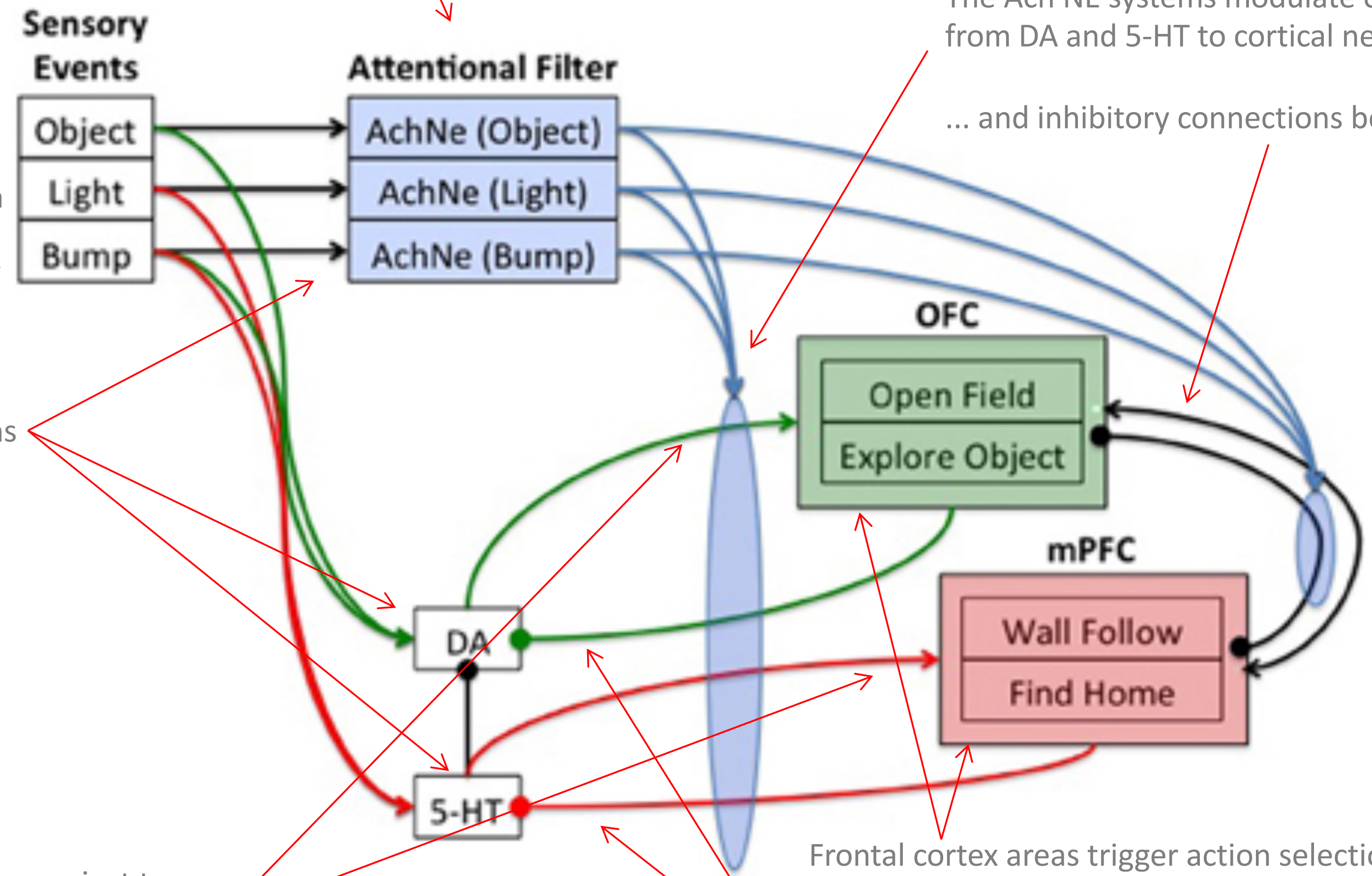
The ACh/NE systems (acetylcholine and noradrenaline) allows novel and unexpected events to gate through to the frontal cortex

Sensory events are handled by three binary neurons
1 when an event occurs,
0 otherwise

All other neurons are governed by a sigmoid activation function

The Ach NE systems modulate connections from DA and 5-HT to cortical neurons ....

... and inhibitory connections between cortical neurons



Sensory events trigger
the neuromodulatory neurons

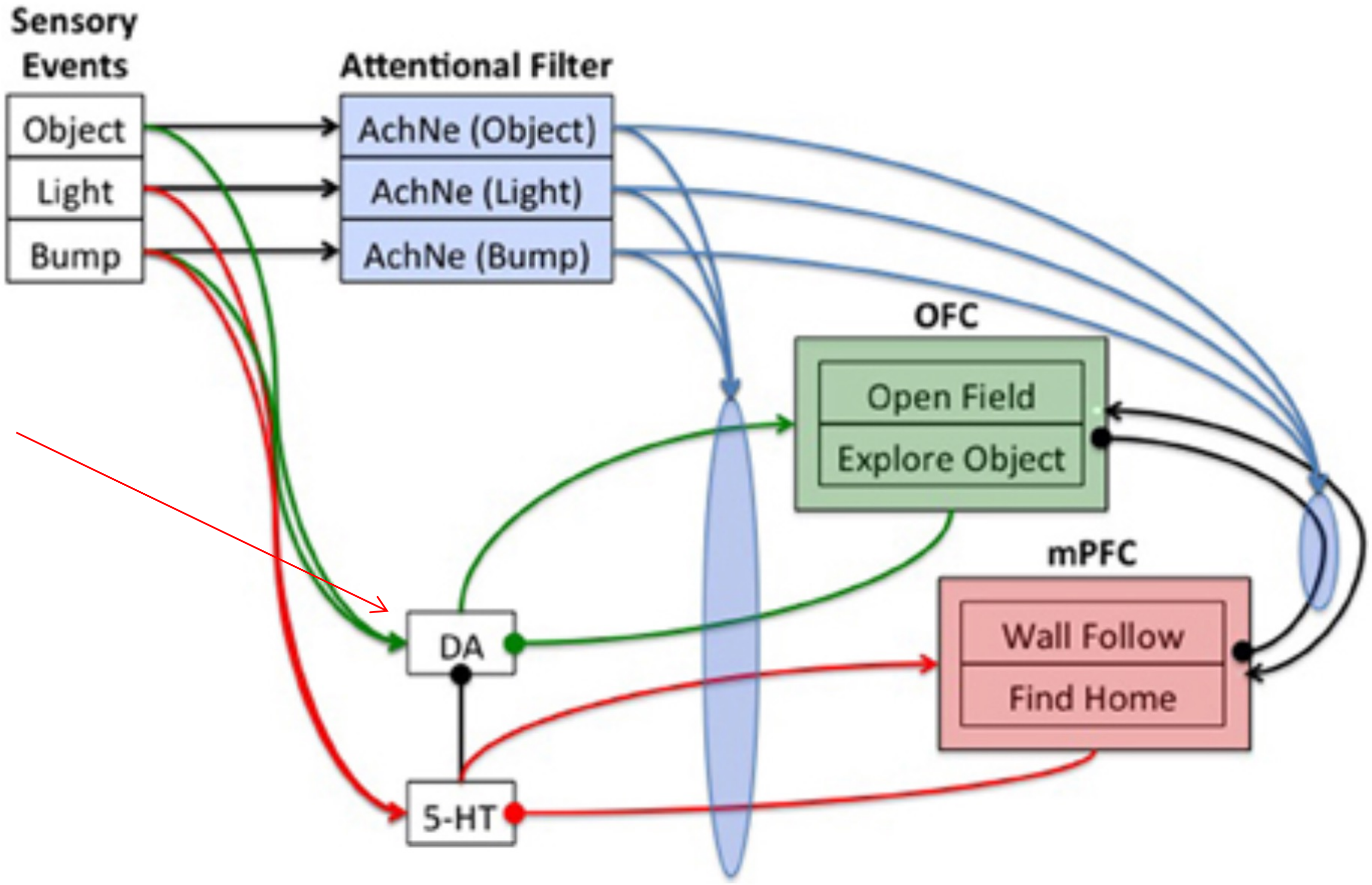
Acetylcholine &
Noradrenaline (ACh/NE)
Dopamine (DA) and
Serotonin (5-HT)

The DA and 5-HT neurons project to the frontal cortex areas OFC and mPFC

Frontal cortex areas trigger action selection and exert cognitive control on the dopaminergic and serotonergic neuromodulatory areas via inhibitory projections.

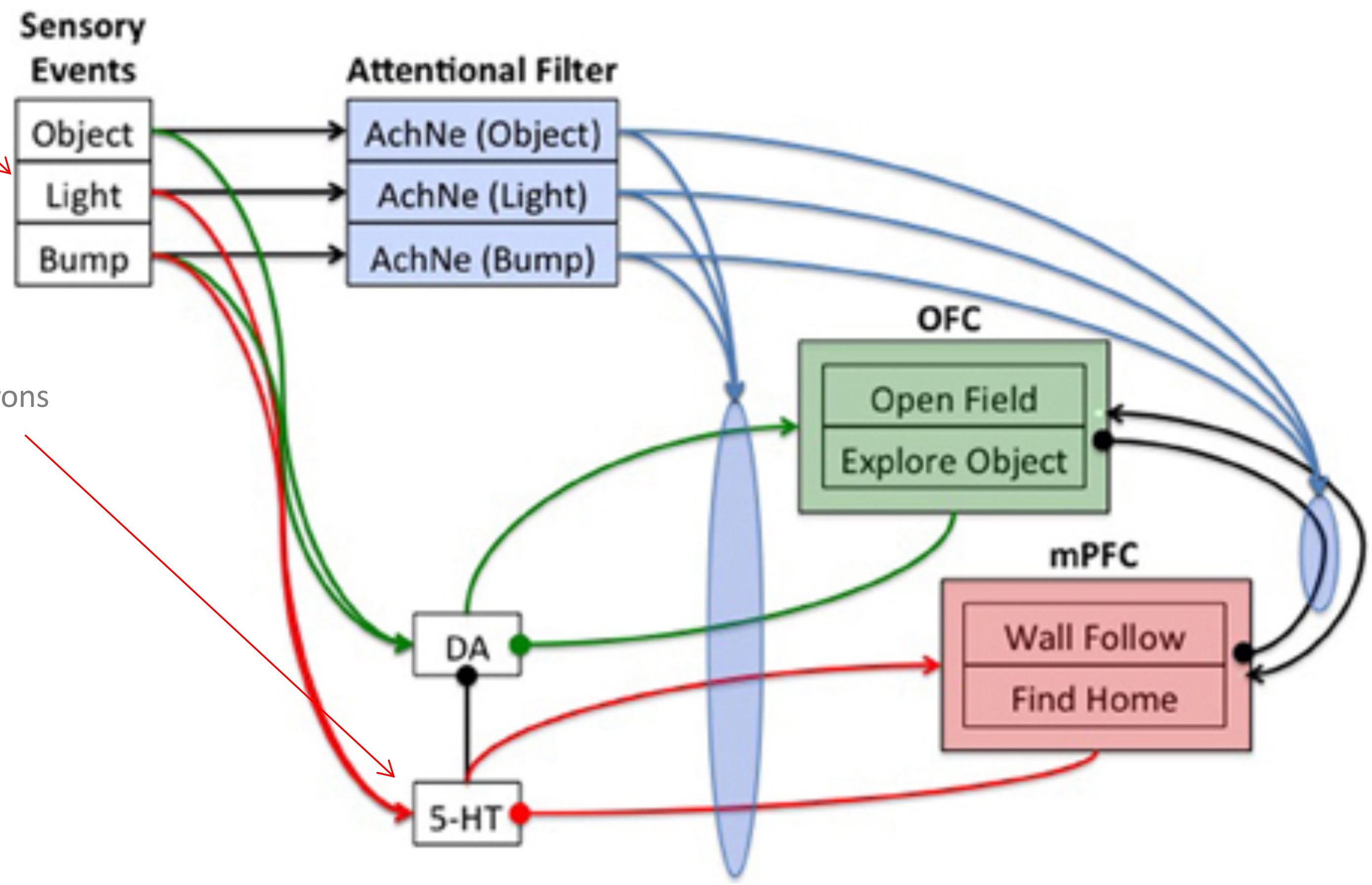
Detecting an object with the laser signals novelty or something potentially rewarding in the environment and worth taking a risk to investigate

Therefore, this event triggered dopaminergic neurons



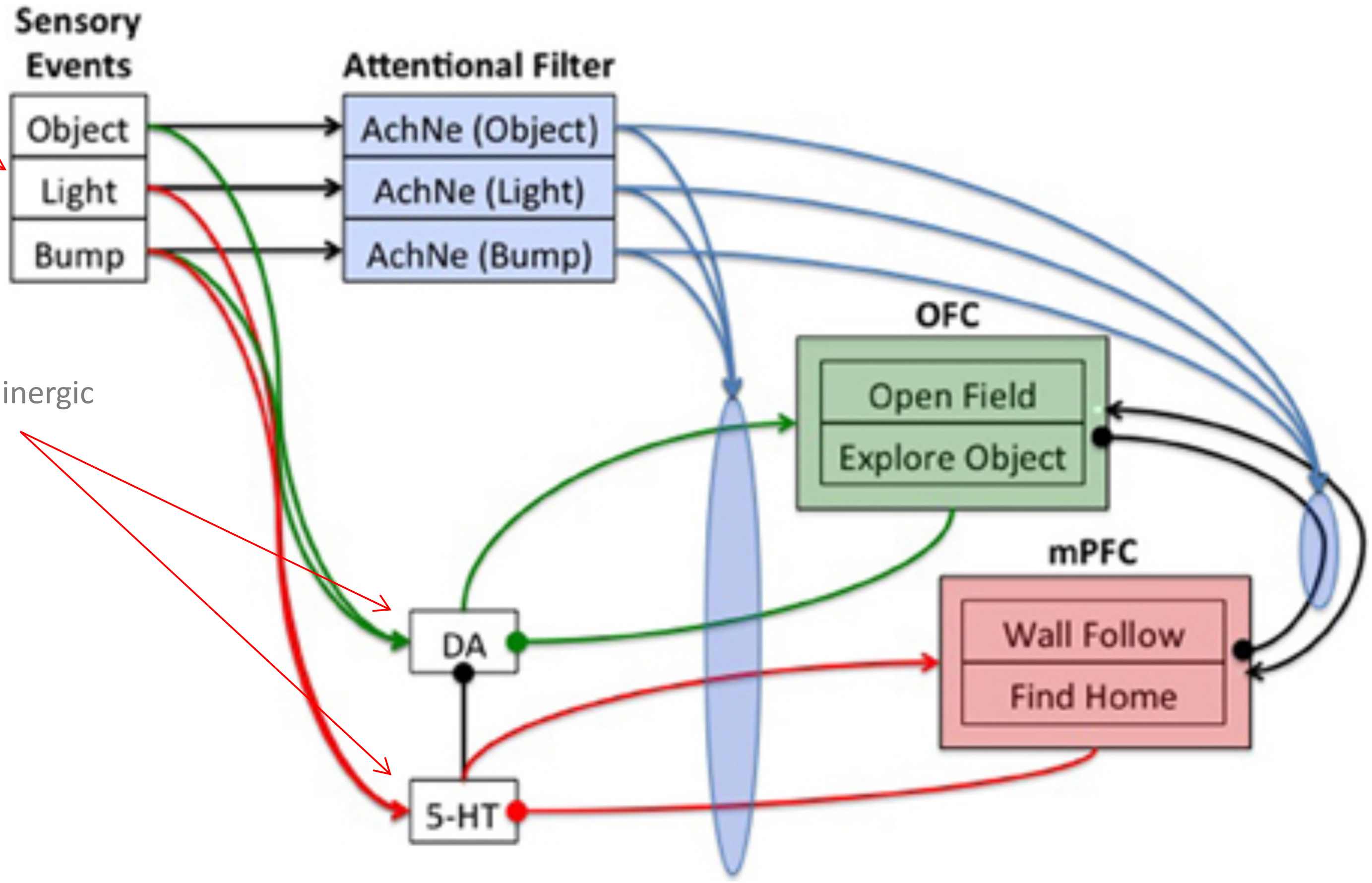
A bright light signals a potential danger

and trigger serotonergic neurons



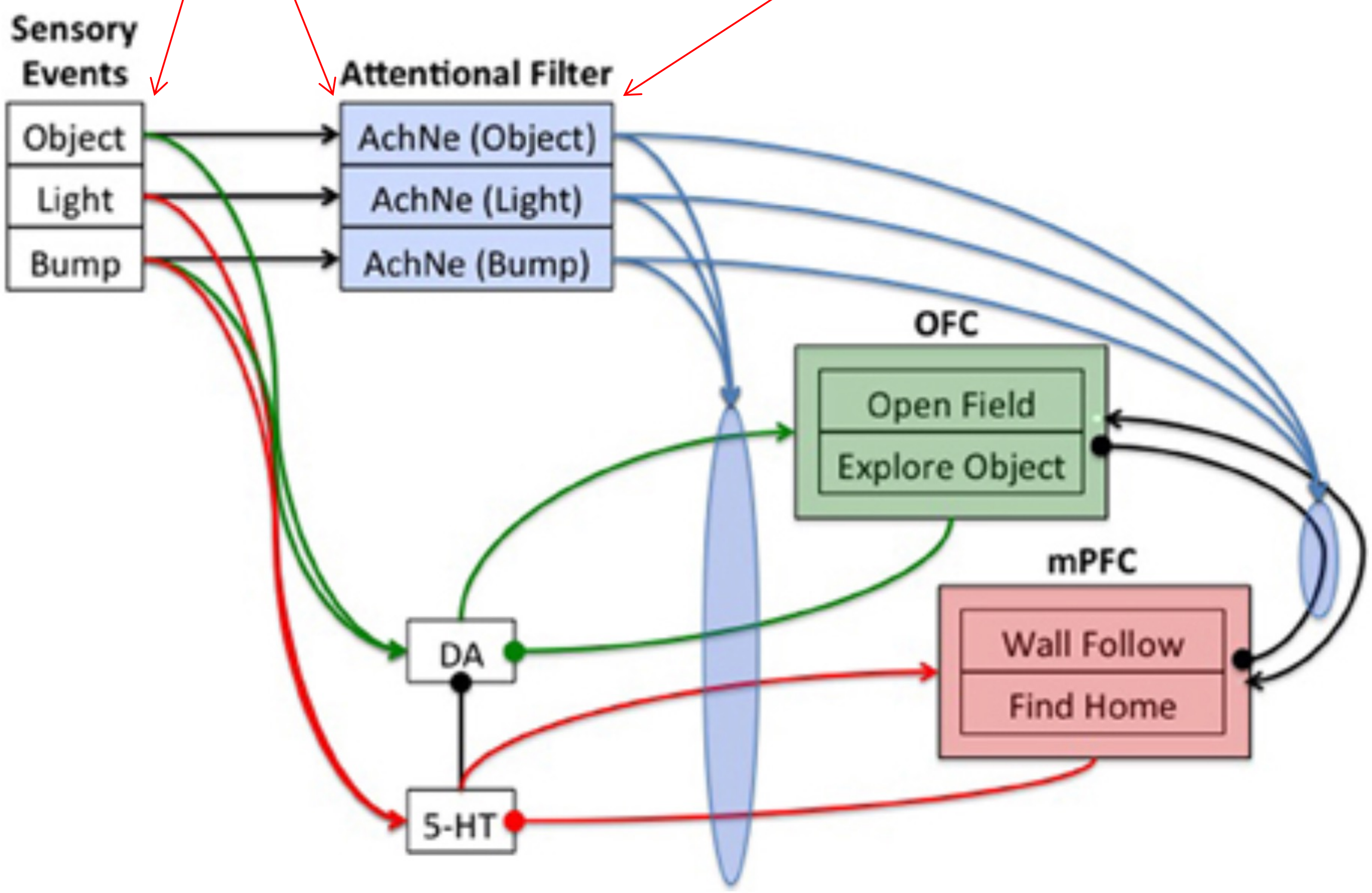
A bump event could signal either something interesting or something noxious in the environment

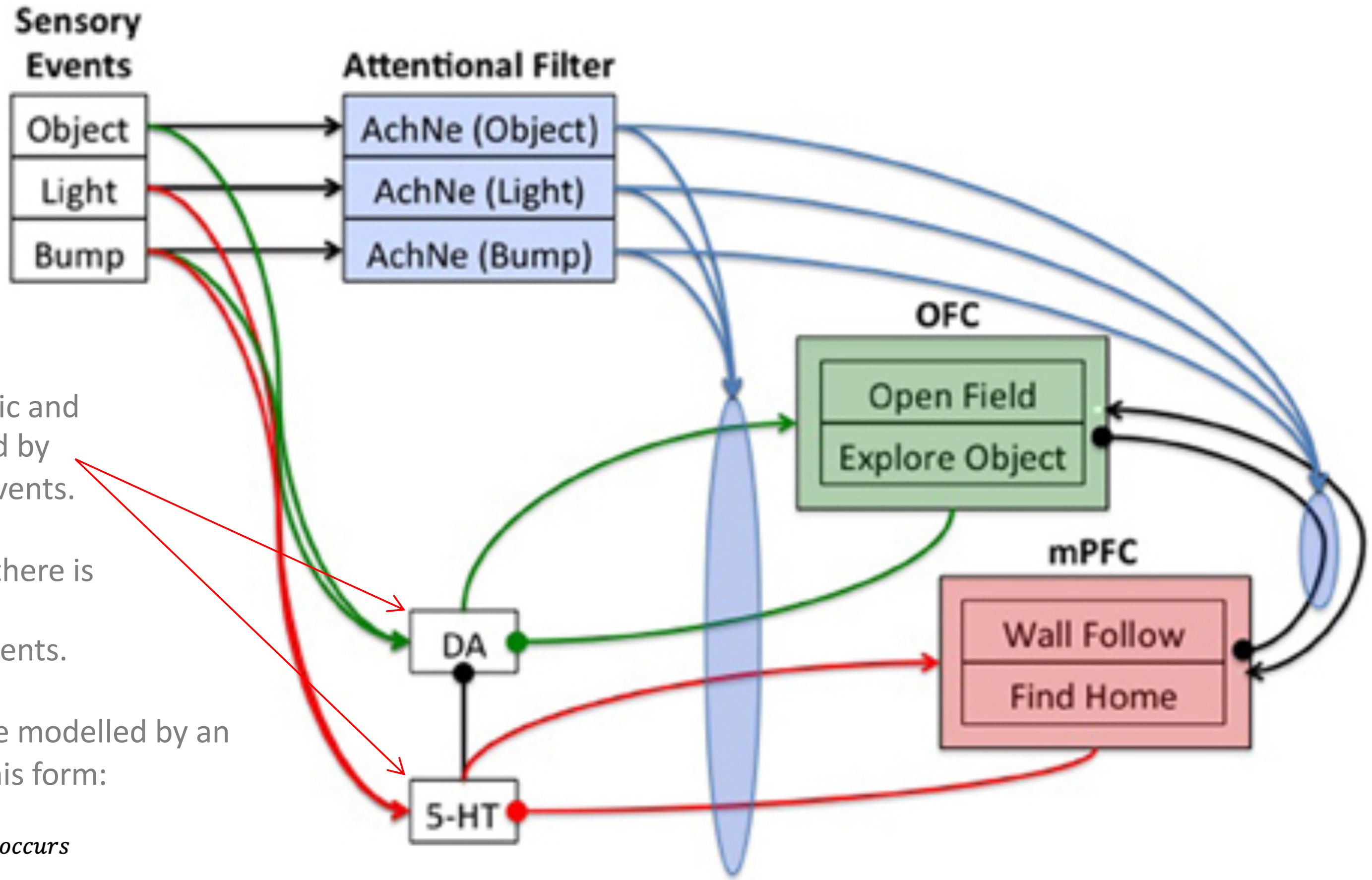
and thus triggers both dopaminergic and serotonergic neurons



The ACh/NE neurons act as attentional filters by adjusting the strength of signals (weights) from event neurons to the ACh/NE system

ACh/NE neurons habituate to frequently occurring events through depressive short-term plasticity using exponential decay





Tonic activity in the dopaminergic and serotonergic neurons is modeled by short-term plasticity that gate events.

The tonic levels rise every time there is a salient sensory event and decay exponentially between events.

These rising and falling levels are modelled by an exponential decay function of this form:

$$nm(t) = \begin{cases} p * nm(t-1); & if\ an\ event\ occurs \\ nm(t-1) + \dfrac{1 - nm(t-1)}{\tau}; & otherwise \end{cases}$$

0.25 for ACh/NE neurons
1.25 for dopaminergic and serotonergic neurons

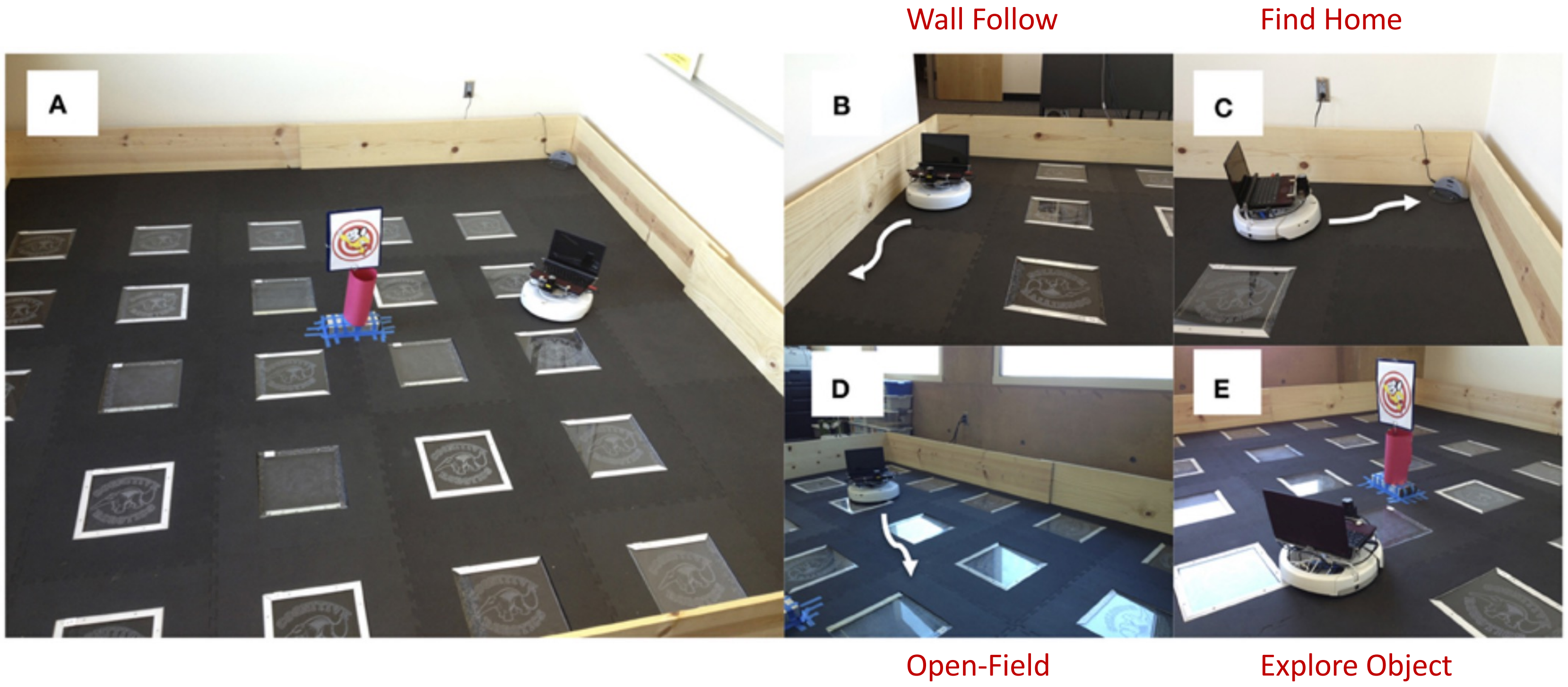
An event occurs for ACh/NE neurons whenever any of the sensory events occurs
An event occurs for DA and 5-HT neurons whenever ACh/NE neuron activity is > 0.5

$$nm(t) = \begin{cases} p * nm(t-1); & if\ an\ event\ occurs \\ nm(t-1) + \dfrac{1 - nm(t-1)}{\tau}; & otherwise \end{cases}$$

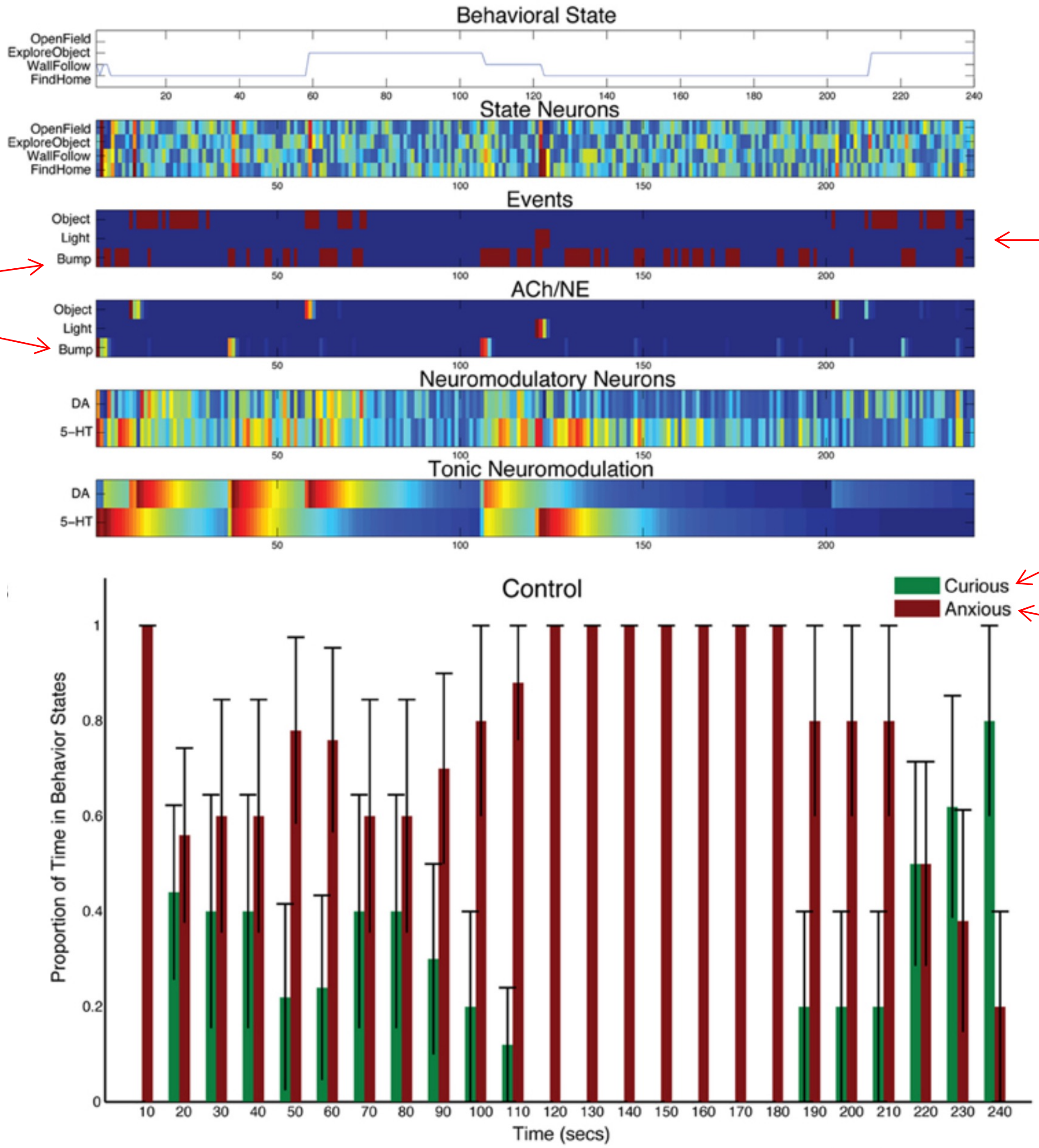
$p < 1$ results in habituation:
the result decreases every time an event occurs

The first time the robot bumps into something there is a strong response in ACh/NE
Subsequent bumps produce a weaker effect on ACh/NE

$p > 1$ has the opposite effect: every time an event is gated for DA and 5-HT, the tonic neuromodulatory response increases


Wall Follow
Find Home
A
B
C
D
E
Open-Field
Explore Object

Rare events triggered by ACh/NE due to habituation



Dark blue: no activity
Red: max activity

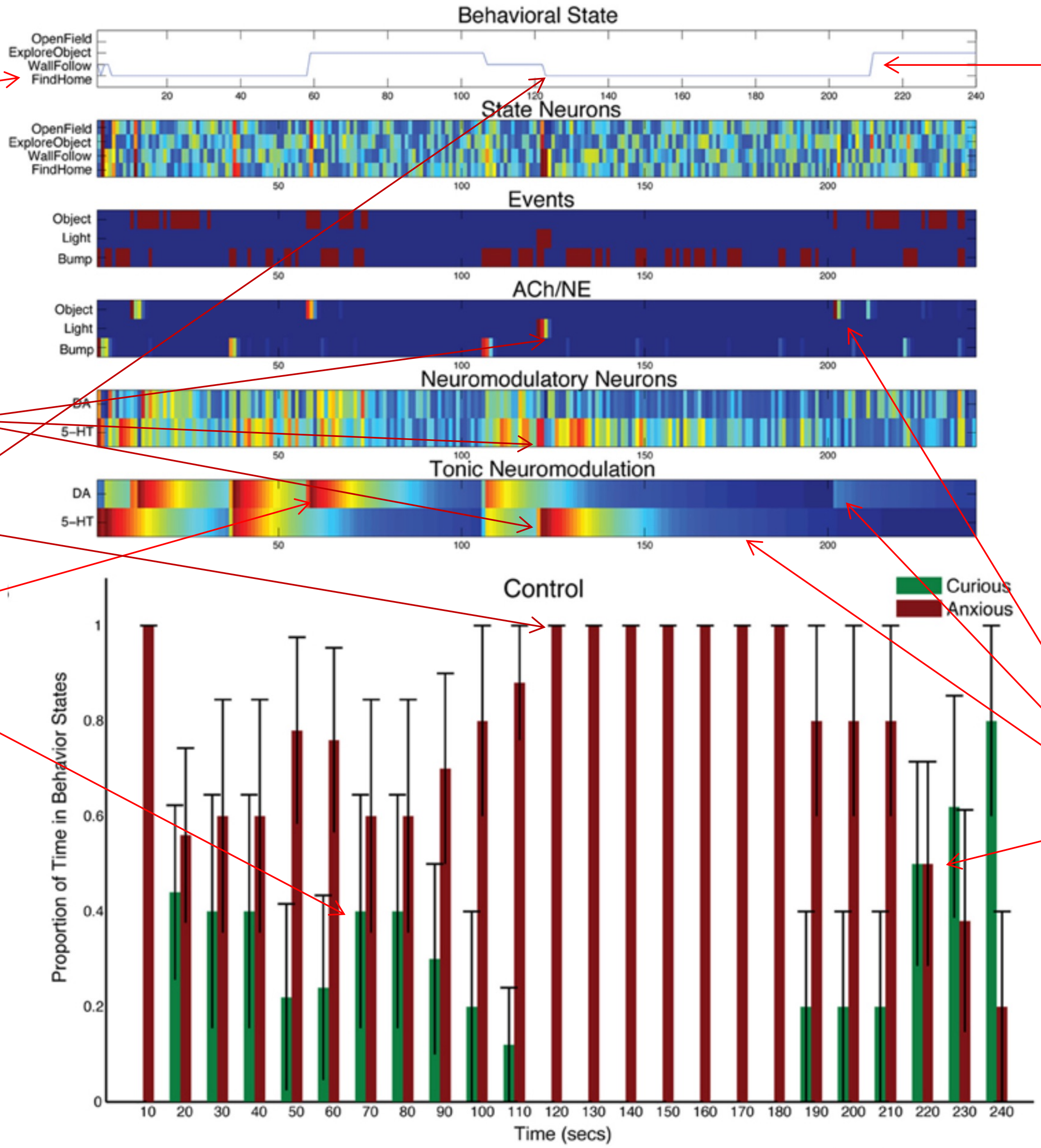
ExploreObject & OpenField behavioral states

FindHome & WallFollow behavioral states

Initially, when the environment is unfamiliar, serotonergic activity dominates, resulting in anxious behavior: WallFollow and FindHome

Phasic and tonic serotonin triggered by light flash, i.e. stress, at 120 seconds resulting in high anxiety and WallFollow behavior

As the robot becomes more familiar, dopaminergic activity increases, resulting in curious behavior: OpenField and ExploreObject



Switch to ExplorObject behavior as tonic DA rises

Switch to ExploreObject behavior as tonic 5-HT decays and object events causetonic DA to rise

The Case Study

Final Observations

- Degrade serotonin uptake
  - Increase the time constant for tonic serotonin: $\tau_{DA} = 50$, and $\tau_{5HT} = 150$
  - Serotonin stays in the system longer after a stressful event, e.g., a bright light
  - A stressful event still causes the robot to select anxious behaviors
  - The increase in serotonin levels resulted in the never breaking out of this stressful behavior

- Increasing the levels of dopamine
  - Increase the time constant for tonic dopamine: $\tau_{DA} = 150$, and $\tau_{5HT} = 50$
  - Results in more curiosity and risk taking but the stress response remains

The Case Study

Final Observations

- The OFC and mPFC areas
  - Effect behavior selection
  - Exert cognitive control on behavior by inhibiting the DA and 5-HT systems
    - This inhibition keeps the appropriate neuromodulatory system in check
    - Exerts cognitive control by signaling to the neuromodulatory system that the sensory event had been handled

The Case Study

Final Observations

- When the projections from mPFC to 5-HT were lesioned in the model
  - The serotonergic system was overactive
  - The robot acted anxious almost entirely
- When the OFC to DA projection was lesioned
  - The robot was overly curious to

We leave the last word to Prof. Jeffrey Krichmar

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Neurorobotic Needs for Artificial General Intelligence

- Follow these Design Principles!
  - Actions and Reactions.
    - Reactive, reflexive, short-term plasticity.
    - Behavioral repertoires.
  - Adaptive Behavior.
    - Learning and memory.
    - Value and Prediction.
  - Behavioral Tradeoffs
    - Opposing environmental needs lead to interesting behavior.
    - Regulated by neuromodulator and hormone levels.

Thank You

Abass, Arisema, Brighton, Emmanuel, Emmanuel, Favour, Geoffrey, Kleber, Medhn, Mucyo, Ola, Opeyemi, and Pamely

for your attention over the past seven weeks

I hope you enjoyed what was a different type of AI-ECE-IT course

Reading

Hwu, T. and Krichmar, J. (2022). Neurorobotics: Connecting the Brain, Body and Environment, MIT Press.

Chapter 6, Section 7.9 , pp. 136 – 143.

References

Boureau, YL., Dayan, P. Opponency Revisited: Competition and Cooperation Between Dopamine and Serotonin. Neuropsychopharmacol 36, 74–97 (2011). https://doi.org/10.1038/npp.2010.151