Technische Universität Wien
Fakultät für !nformatik
Cyber-Physical-Systems Group

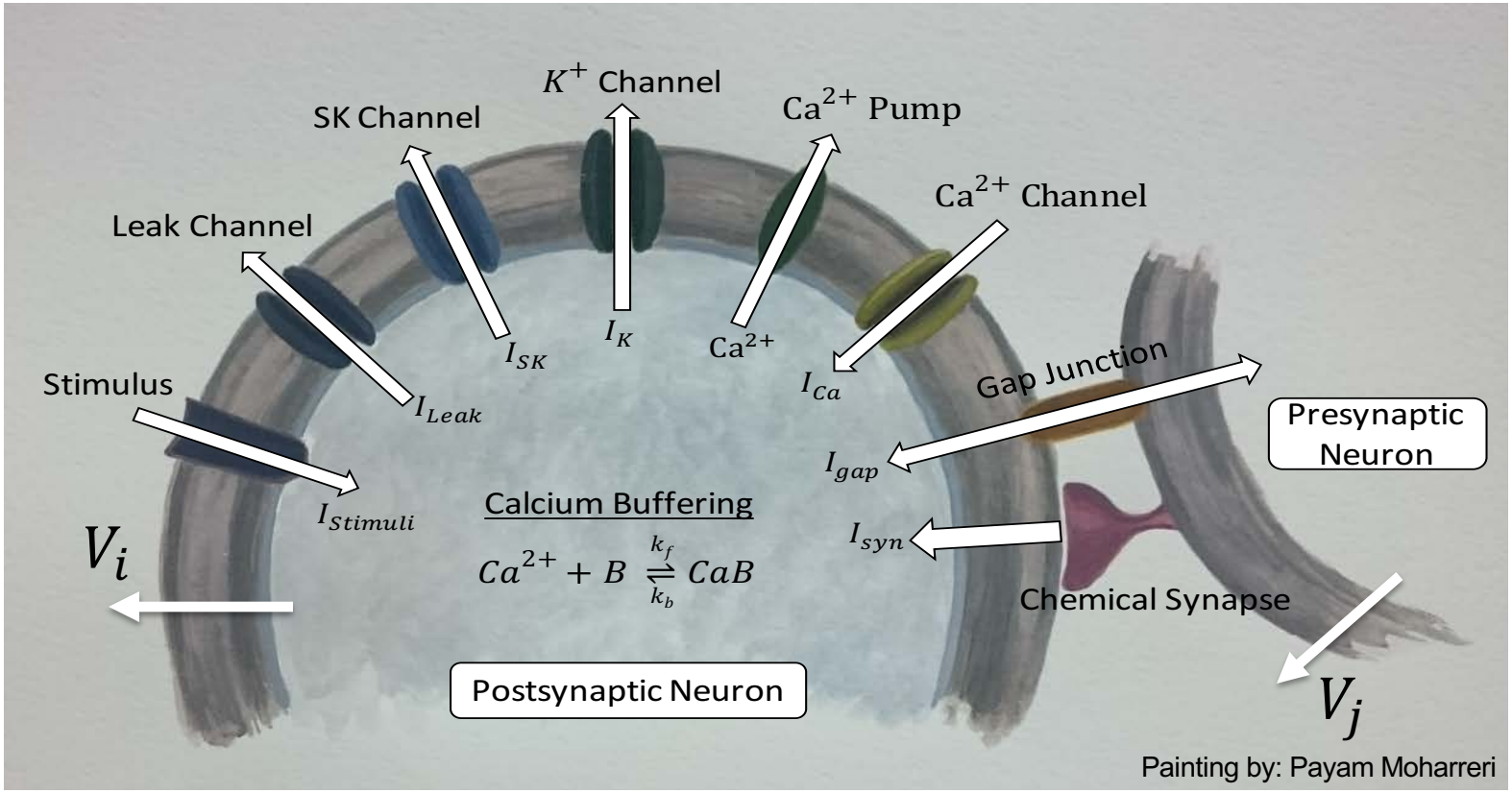
Neural Circuit Policies
Enabling Auditable Autonomy

Radu Grosu

The Exquisite Brain of C. elegans

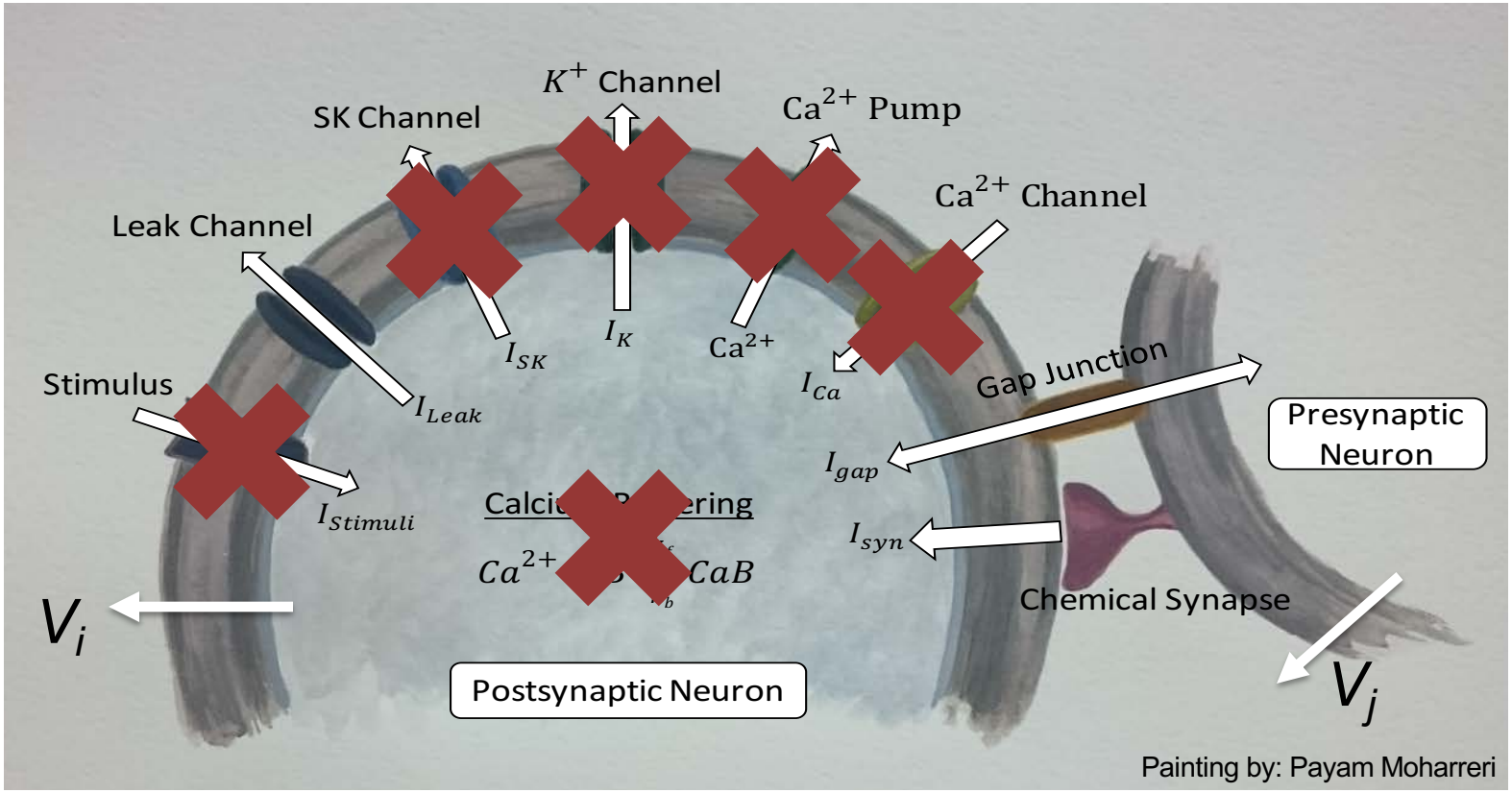
- L: 1mm, W: 0.01mm
- 302 nonspiking neurons
- 8000 synapses
- 95 body-wall muscles
- Associative learning
- Social behavior
- Connectome fully mapped

Biophysical Neuron Model



$$C_i \dot{V}_i = -\left(I_{Ca} + I_K + I_{SK} + I_{leak,i}\right) + I_{stim,i} + \sum_j I_{syn,ji} + I_{gap,ji}$$

Biophysical Neuron Model



$$C_i \dot{V}_i(t) = I_{leak,i}(t) + \sum_j (I_{syn,ji}(t) + I_{gap,ji}(t))$$

Currents in the Biophysical Model

$$C_i \dot{V}_i(t) = I_{leak,i}(t) + \sum_j (I_{syn,ji}(t) + I_{gap,ji}(t))$$

Leakage Current

$$I_{leak,i}(t) = g_{l,i}(E_{l,i} - V_i(t))$$

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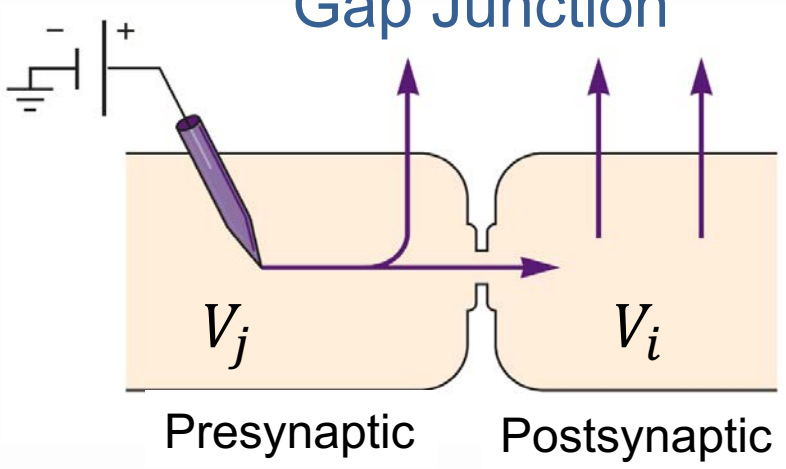
Gap Junction



$$I_{gap,ji}(t) = g_{g,ji}(V_j(t) - V_i(t))$$

Currents in the Biophysical Model

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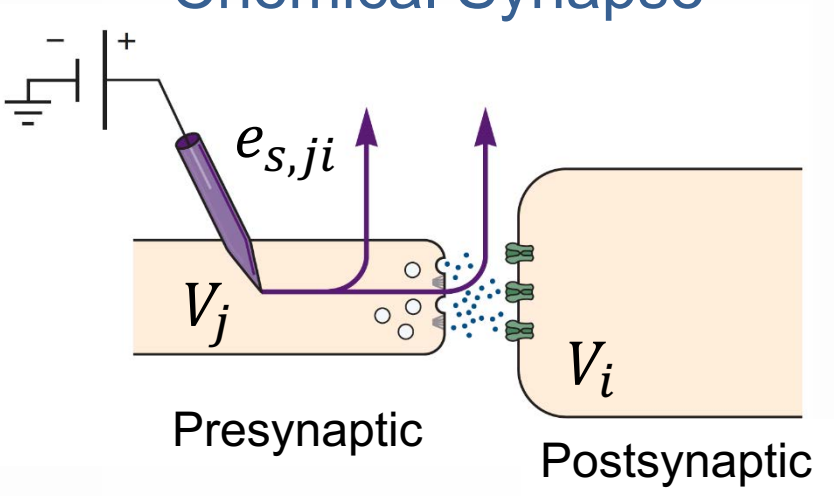
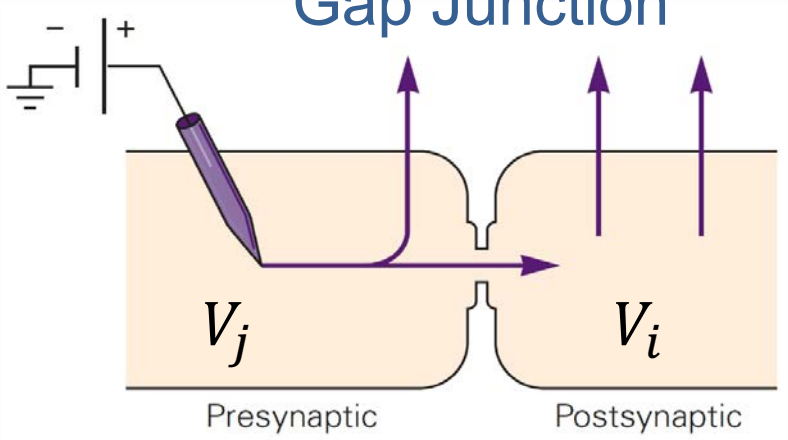
Chemical Synapse



$$I_{syn,ji}(t) = g_{s,ji}\sigma(V_j(t), \mu_j)(E_{s,ji} - V_i(t))$$

Gap Junction



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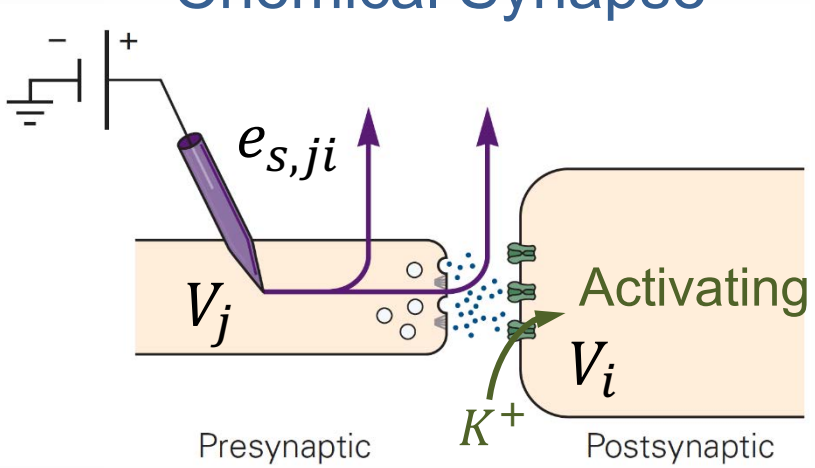

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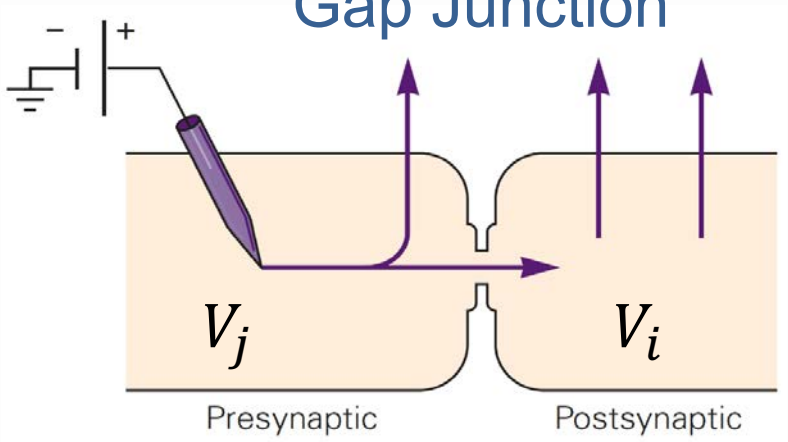

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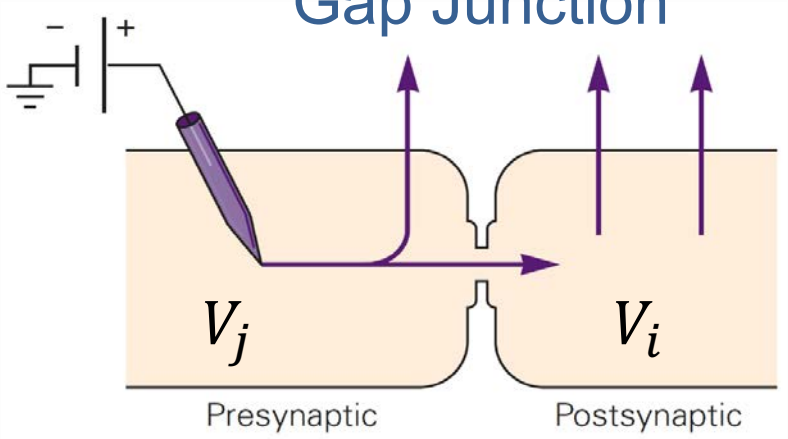
Gap Junction



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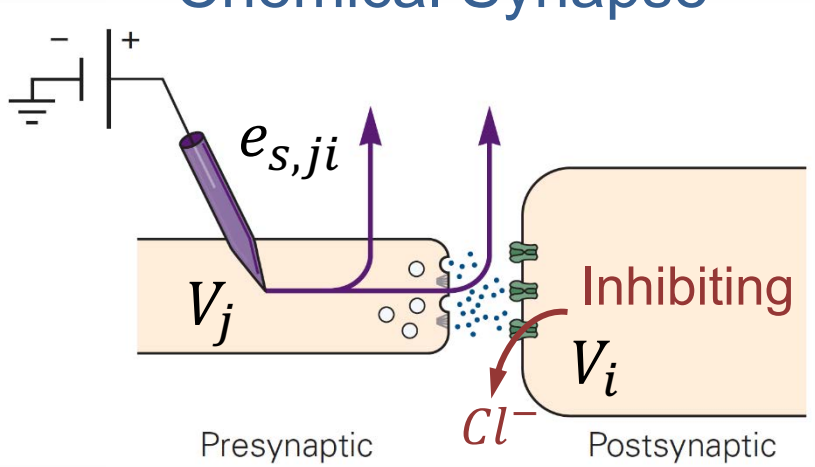

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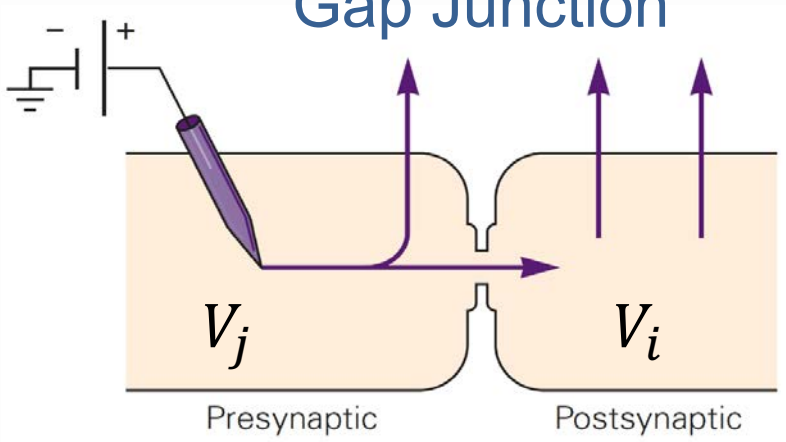

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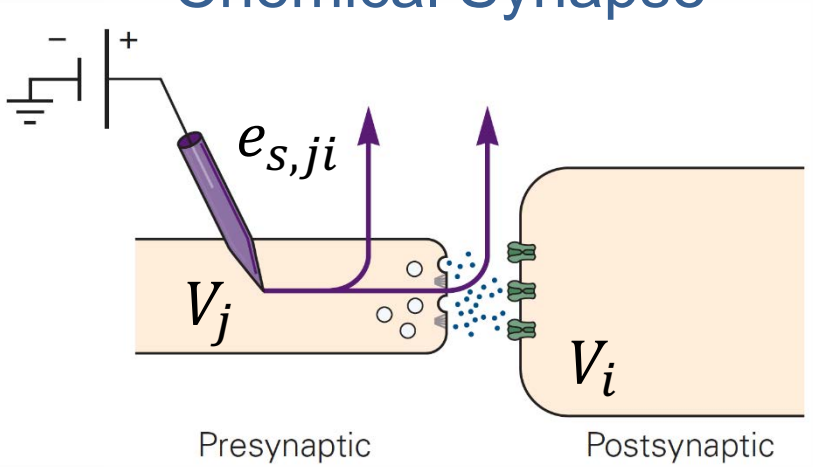
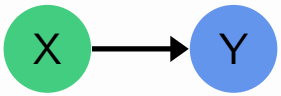
Chemical Synapse

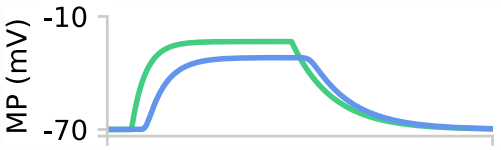


$$I_{syn,ji}(t) = g_{s,ji}\sigma(V_j(t), \mu_j)(E_{s,ji} - V_i(t))$$

$$\sigma(V_j(t), \mu_j) = \frac{1}{1 + e^{-(V_j(t) - \mu_j)}}$$

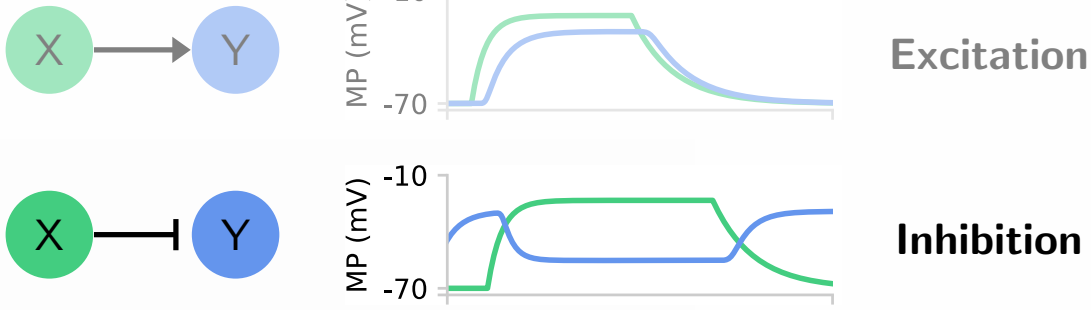
Primitive Policy Motifs



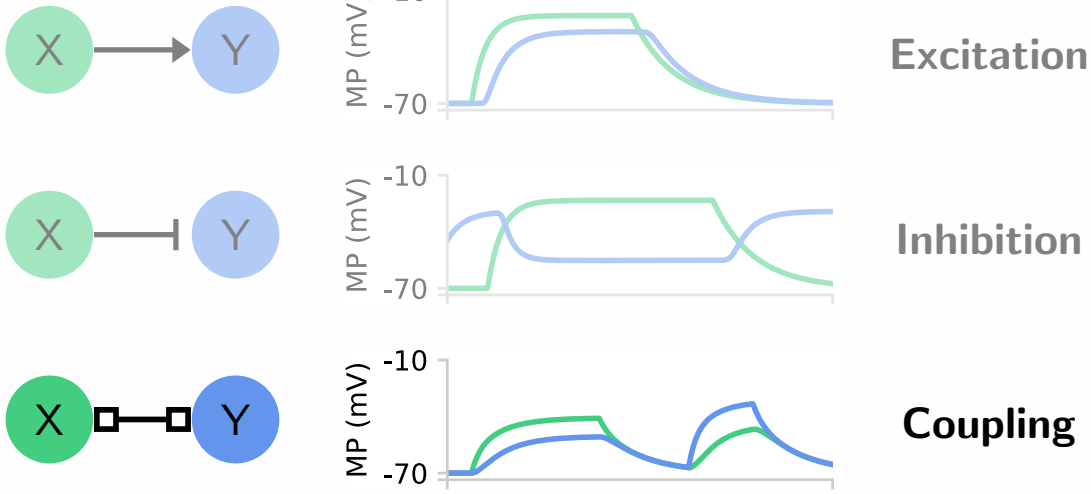


Excitation

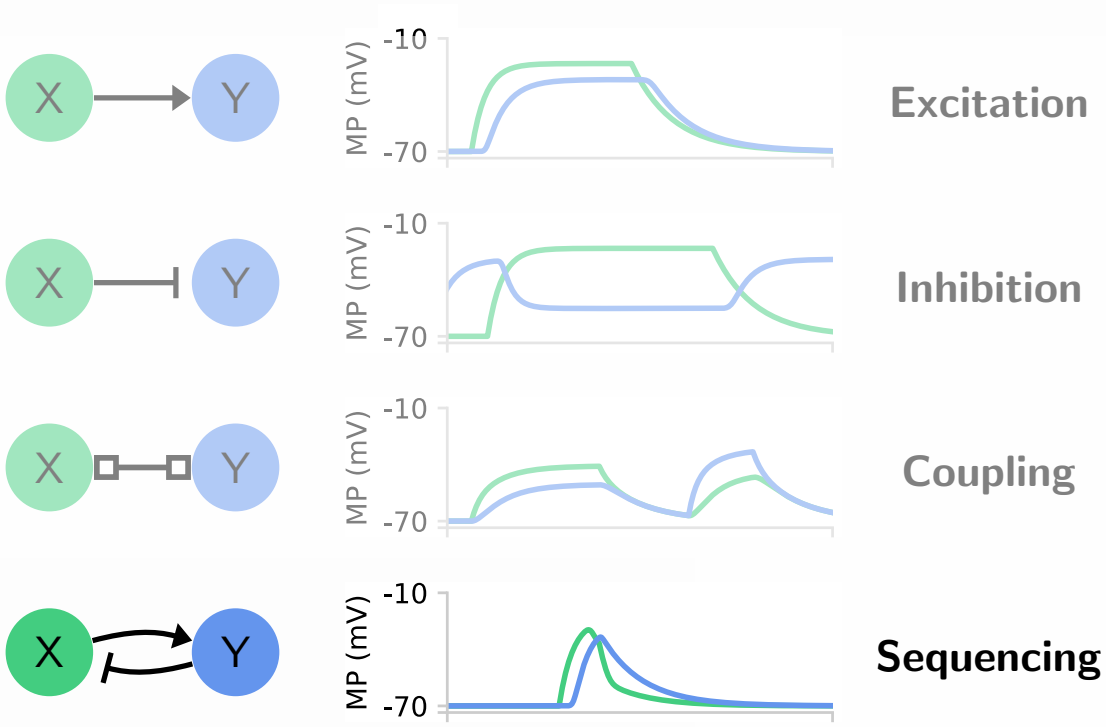
Primitive Policy Motifs



Primitive Policy Motifs



Feedback Policy Motifs



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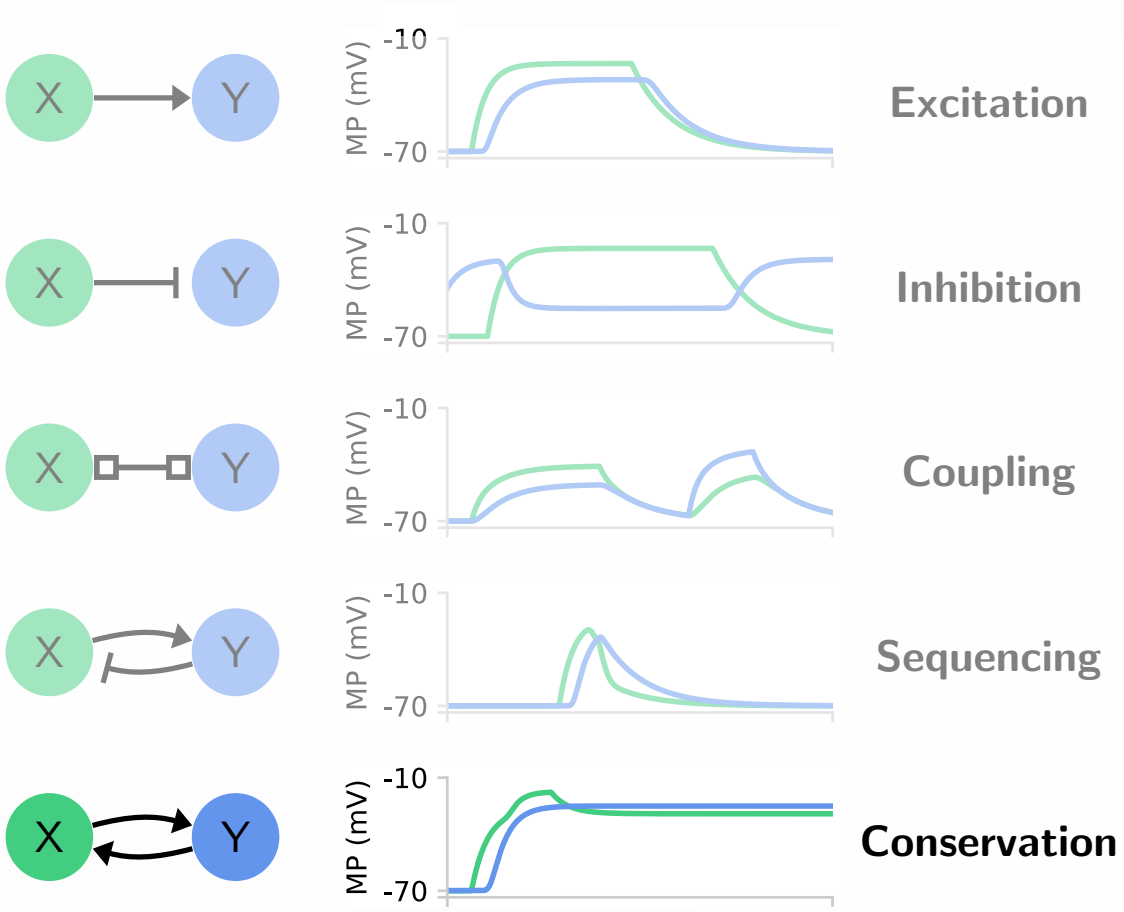
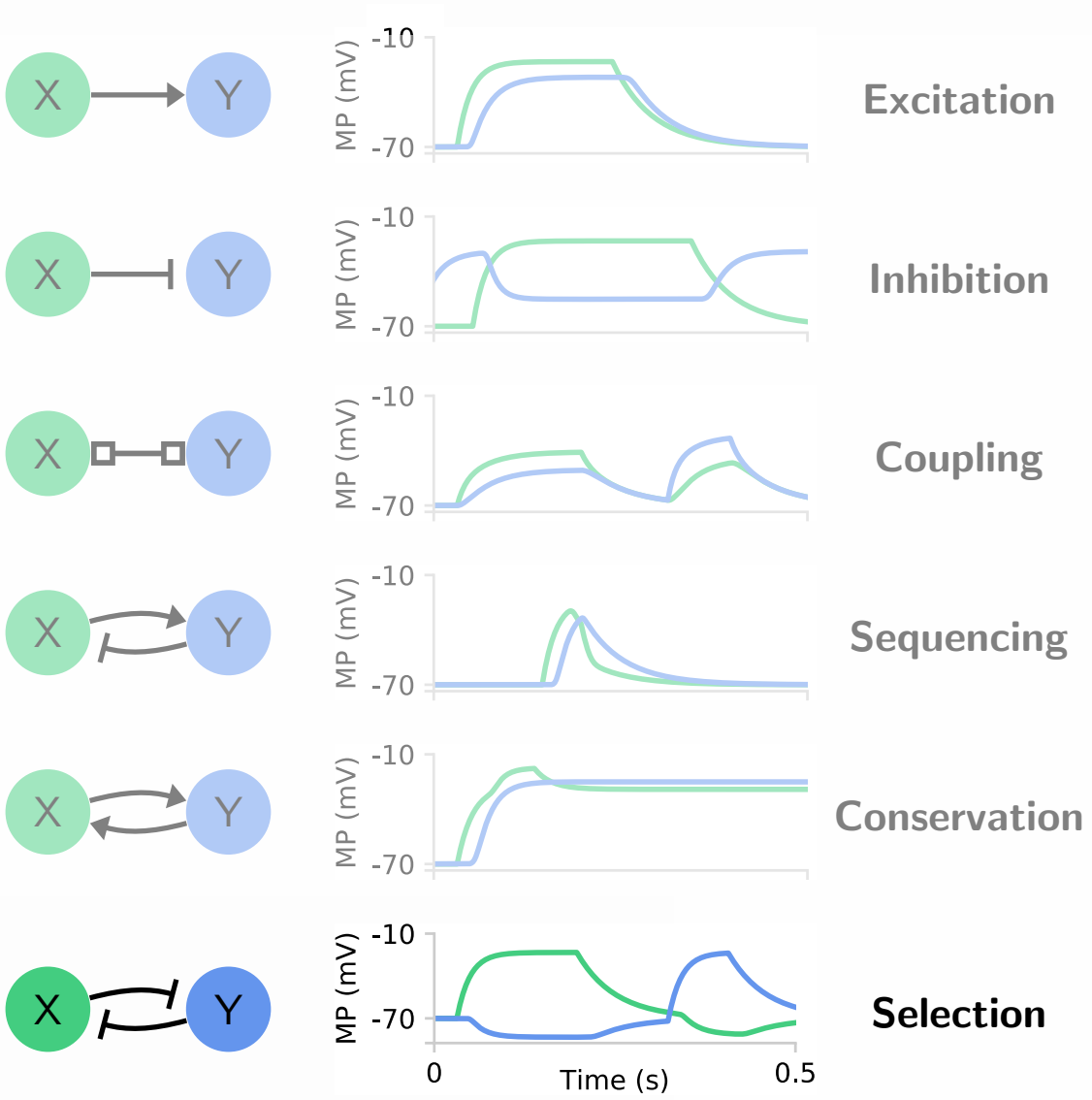


Feedback Policy Motifs



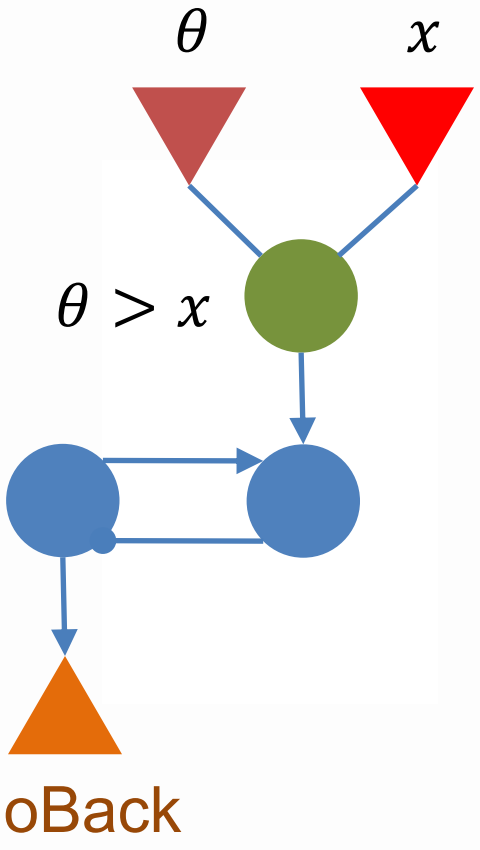
Policy Motifs: Example

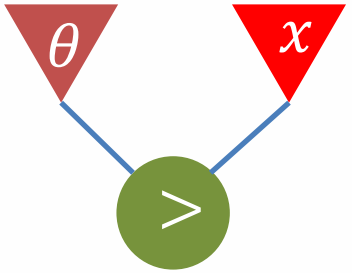
Sensory Neurons

Inter Neurons

Command Neurons

Motor Neurons

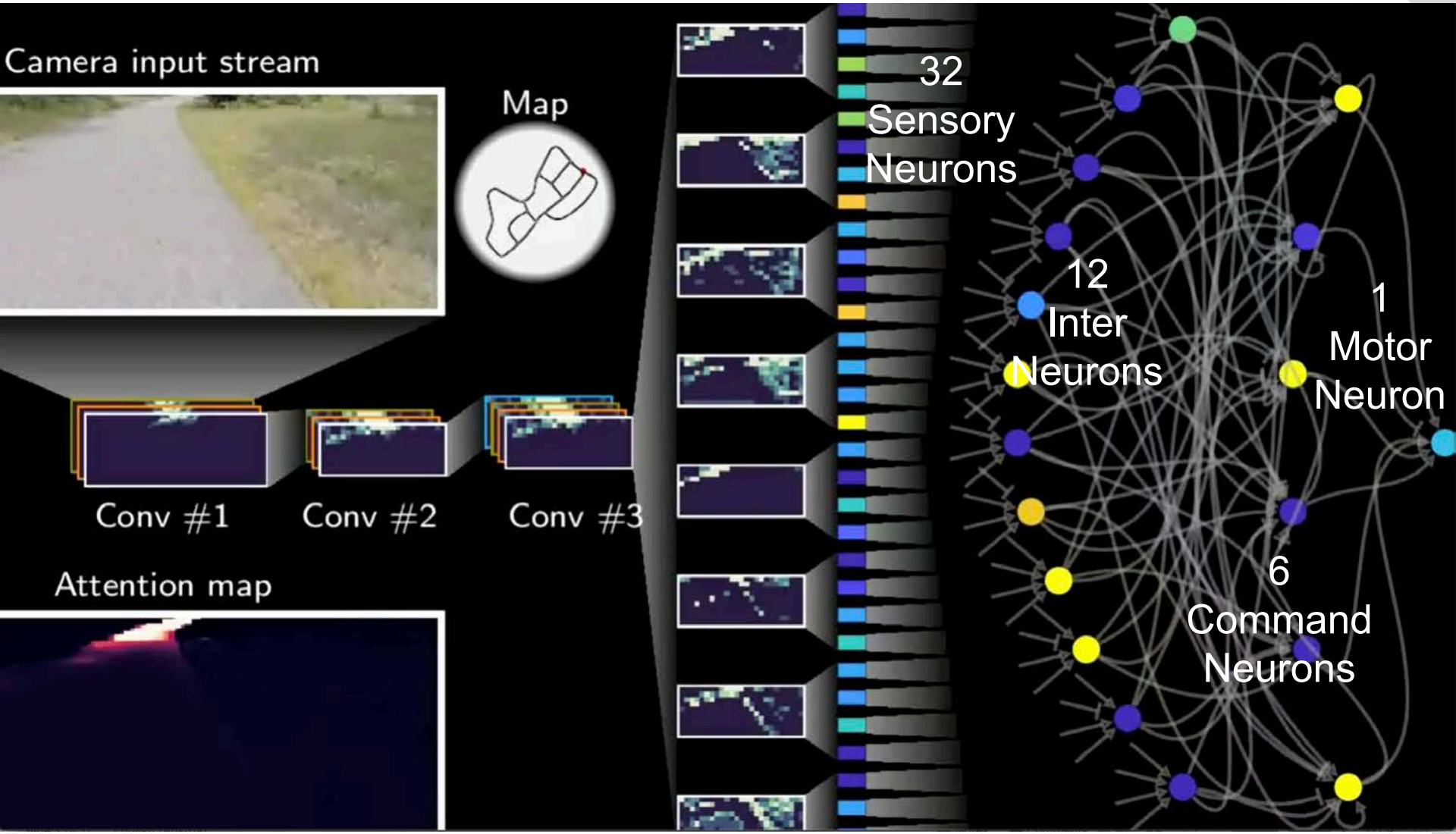




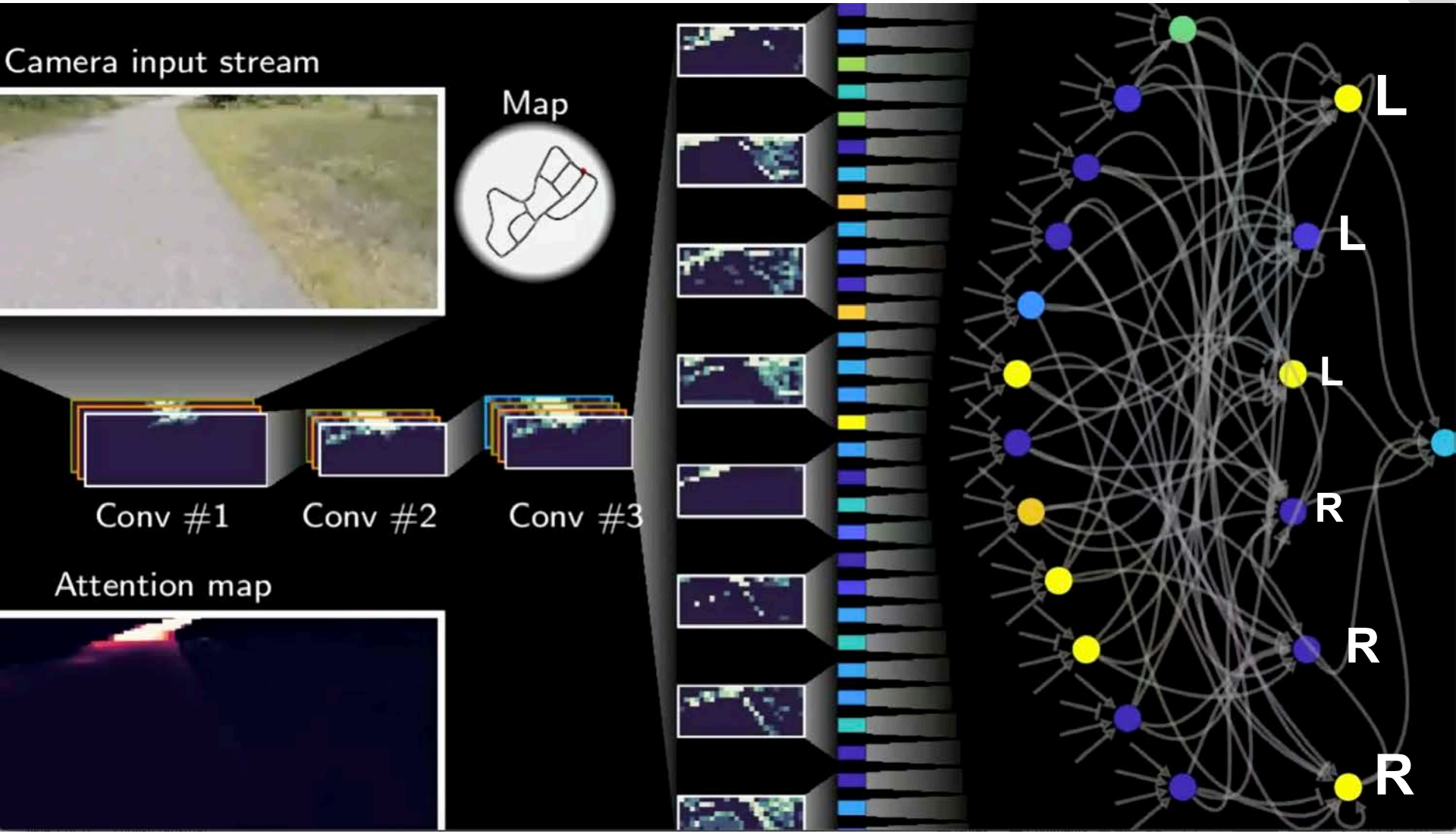
while $(\theta \leq x)$

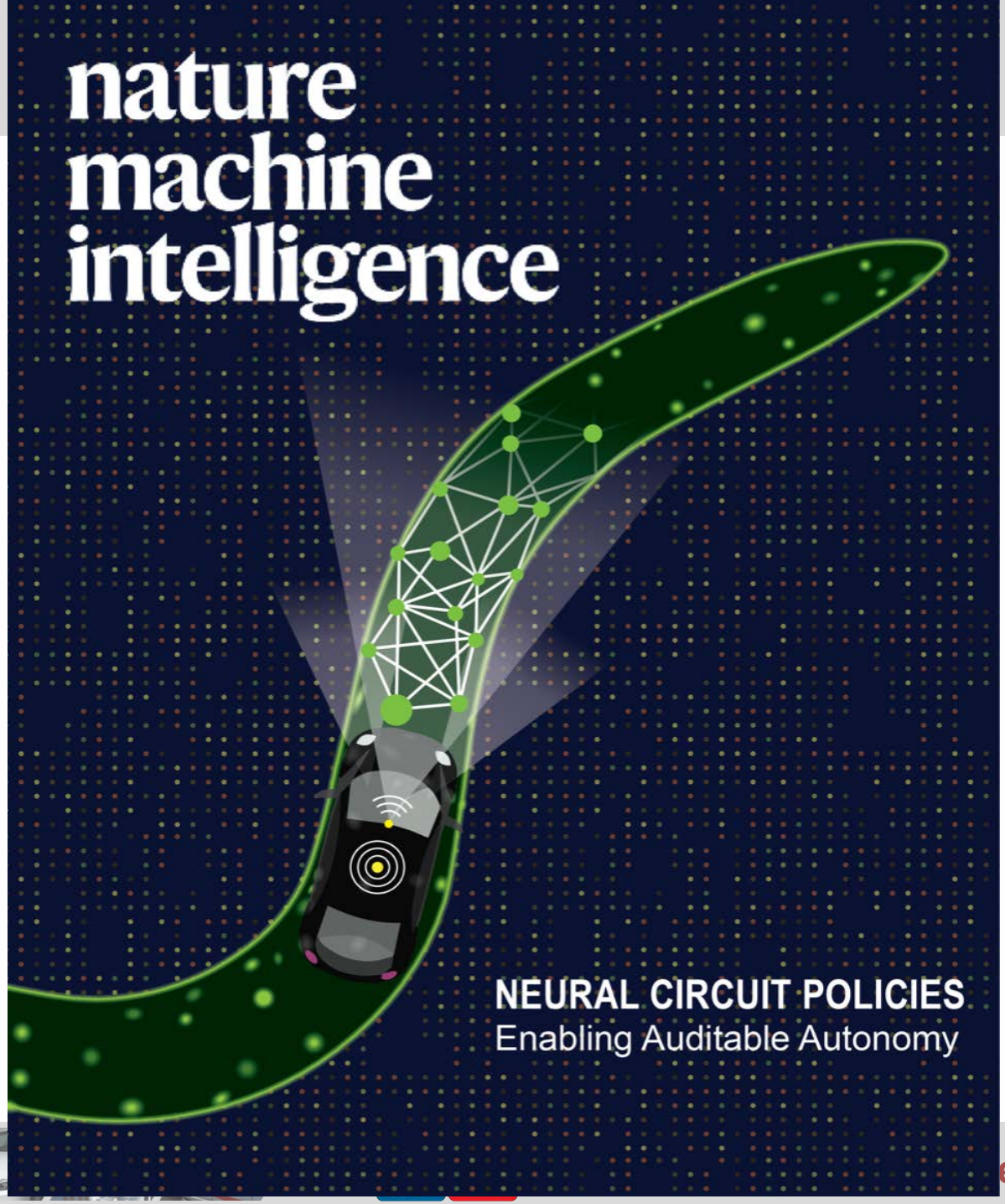
goBack

NCP Architecture for Lane Keeping

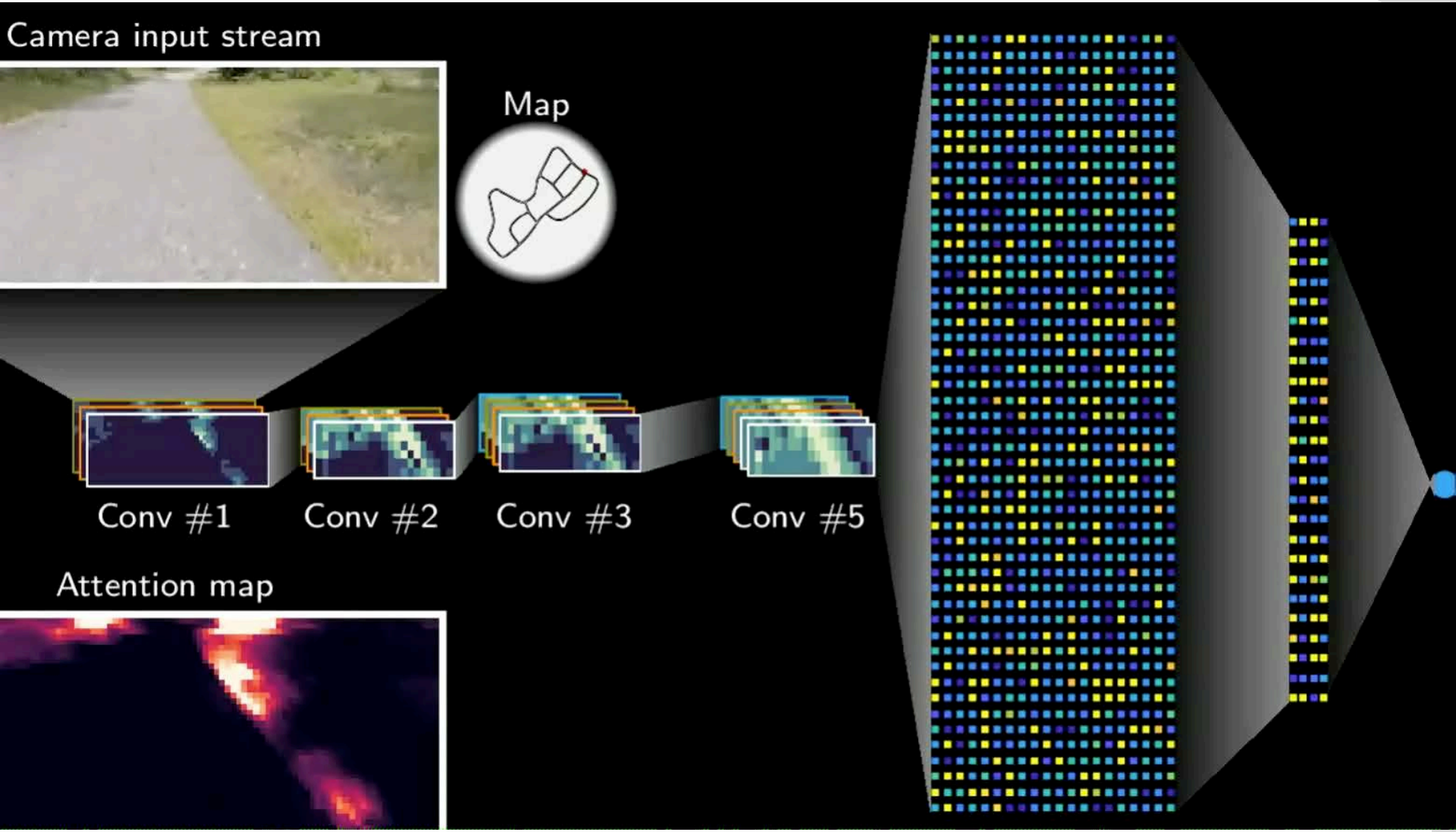


NCP Architecture for Lane Keeping

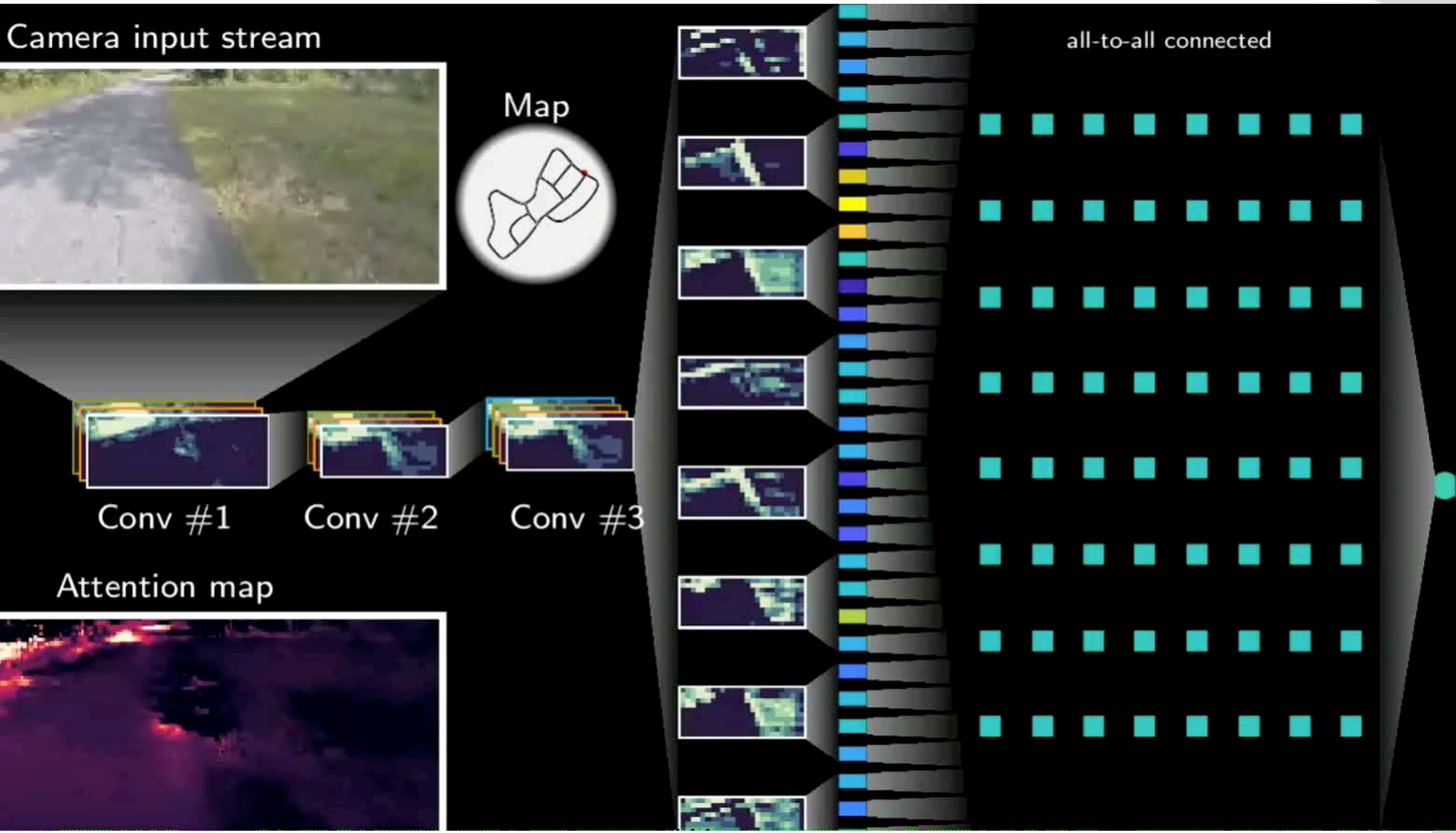



nature
machine
intelligence
NEURAL CIRCUIT POLICIES
Enabling Auditable Autonomy

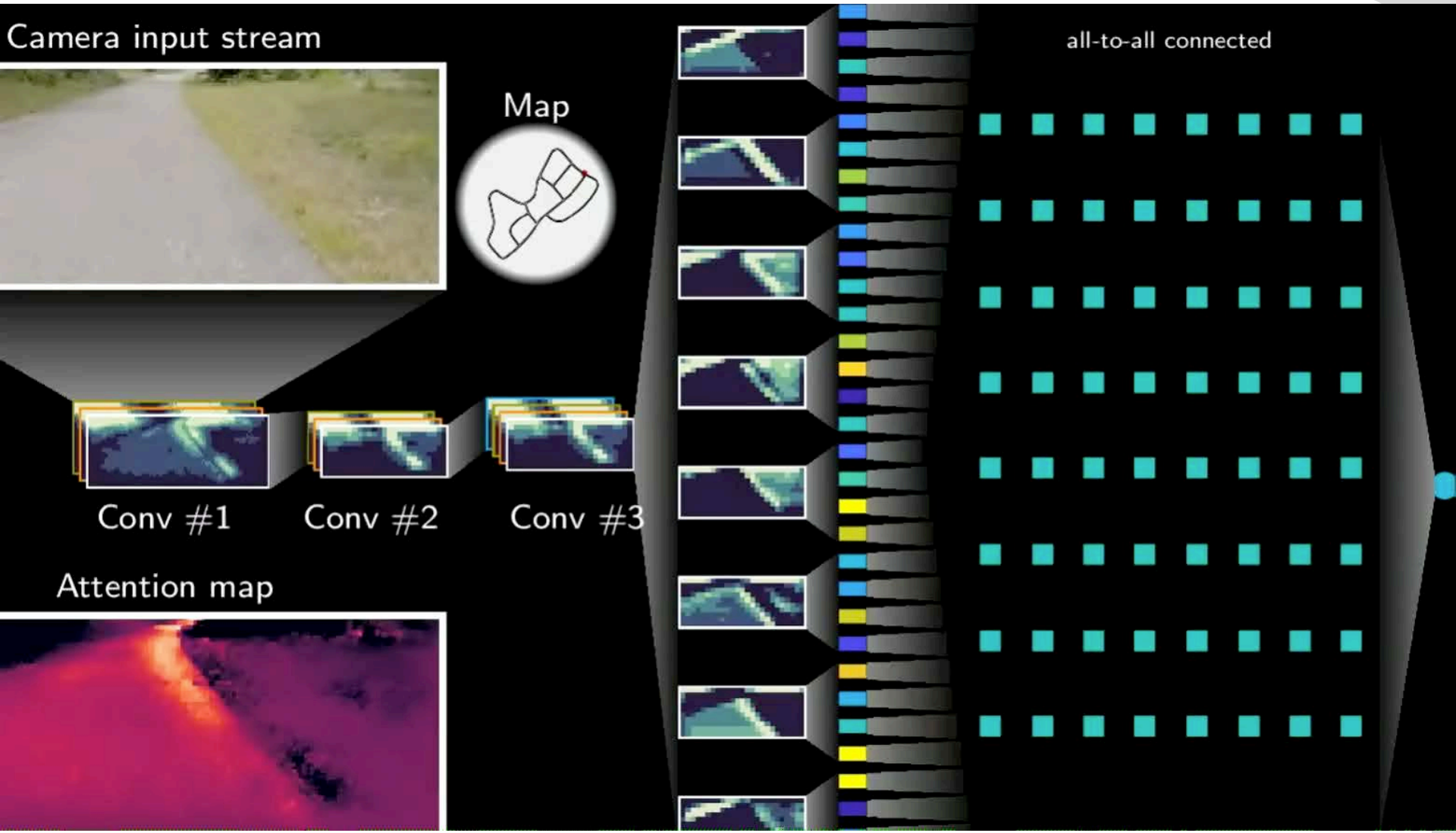
Convolutional Neural Networks in Action



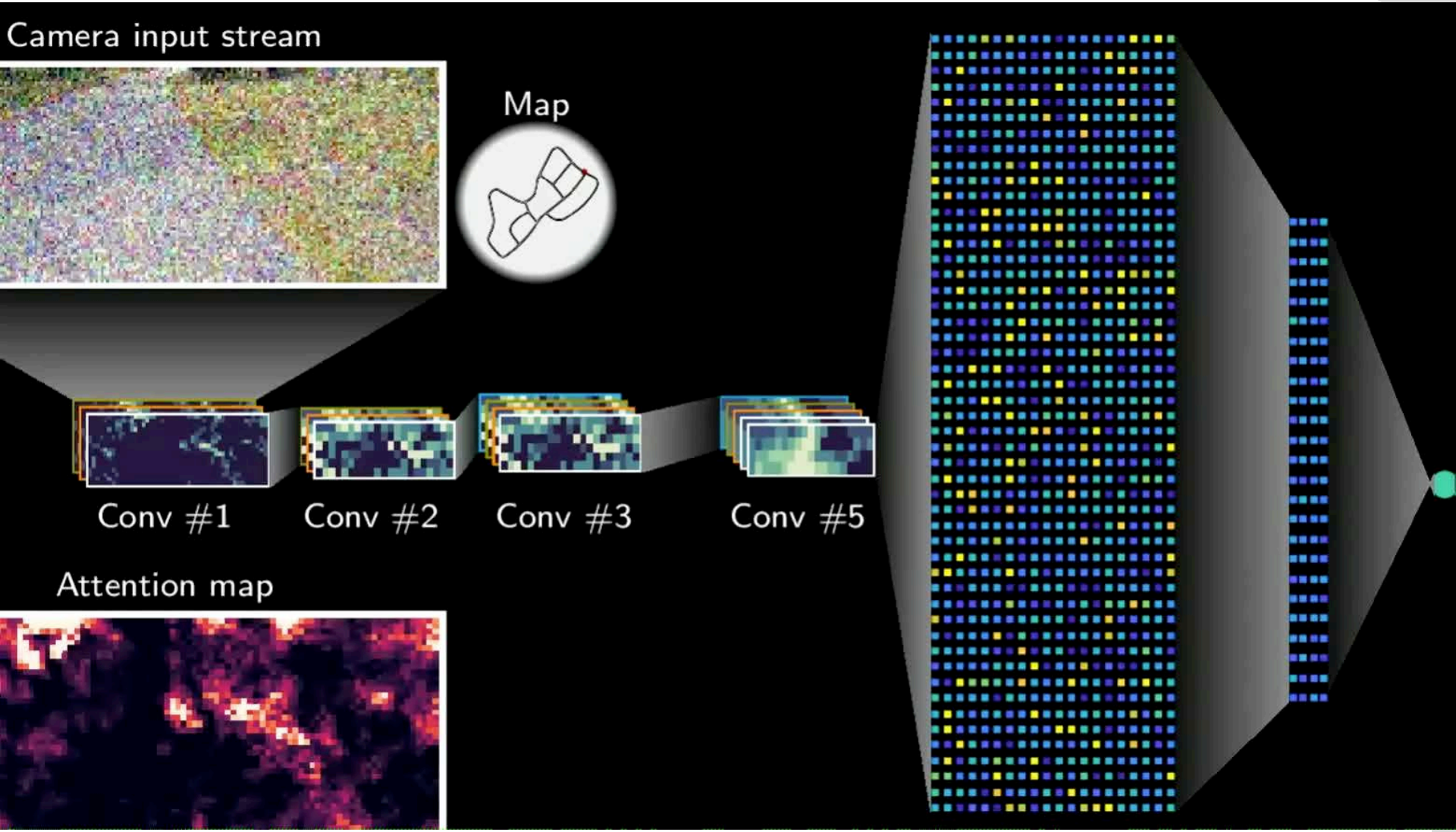
Continuous-Time RNNs in Action



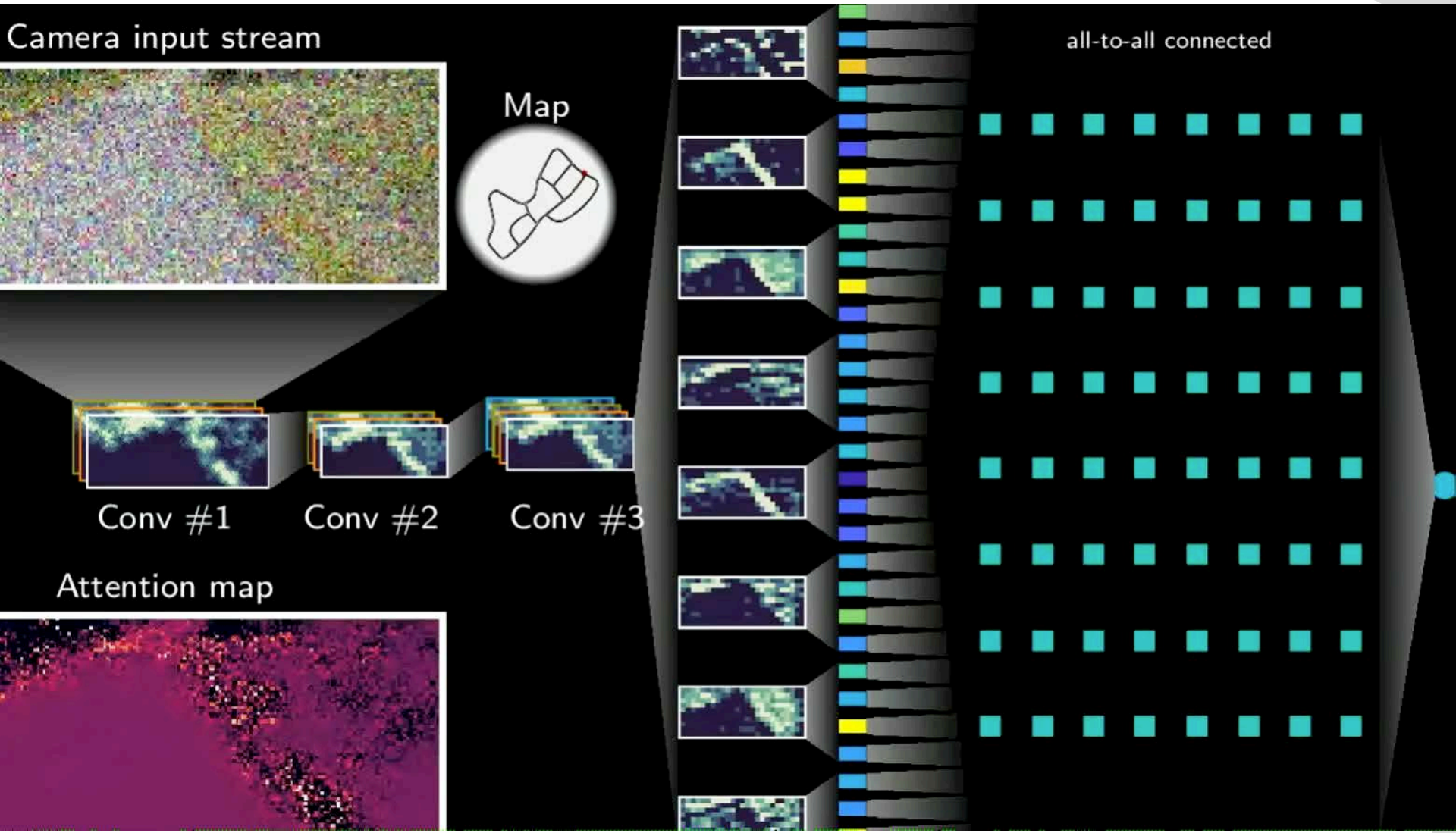
Long-Short-Term-Memory NNs in Action



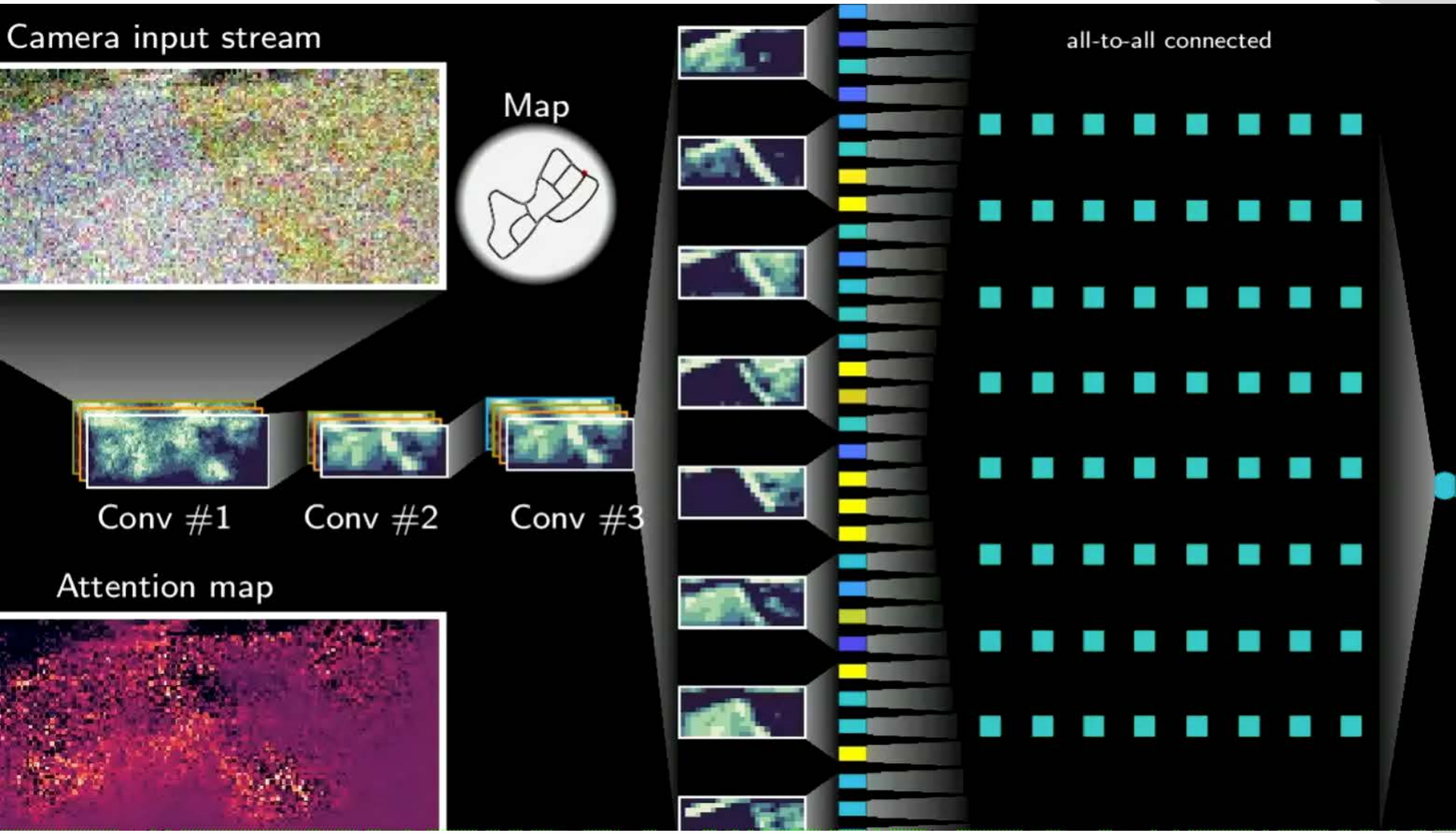
Convolutional Neural Networks: Noisy Input



Continuous-Time RNNs: Noisy Input

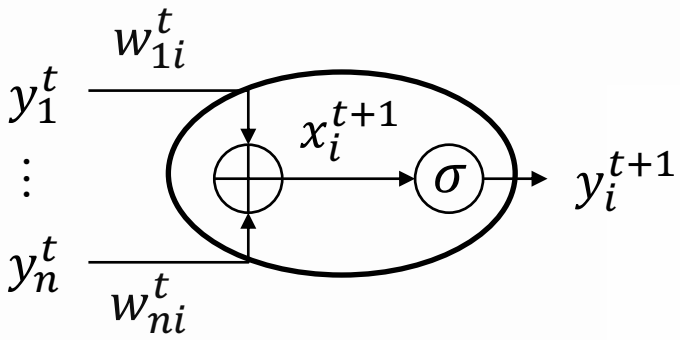


Long-Short-Term-Memory NNs: Noisy Input



From Artificial to Biophysical Neurons

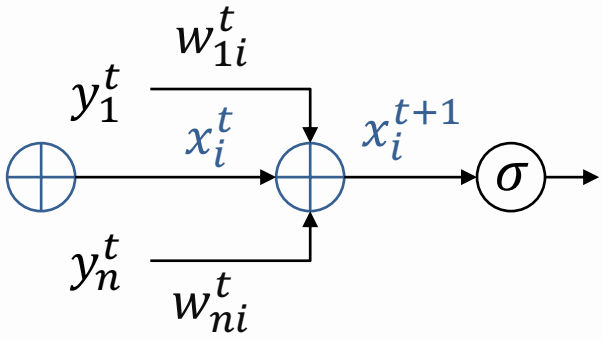
DNNs:



$$x_i^{t+1} = \sum_j w_{ji}^t y_j^t$$

$$y_j^t = \sigma(x_j^t, \mu_j^t)$$

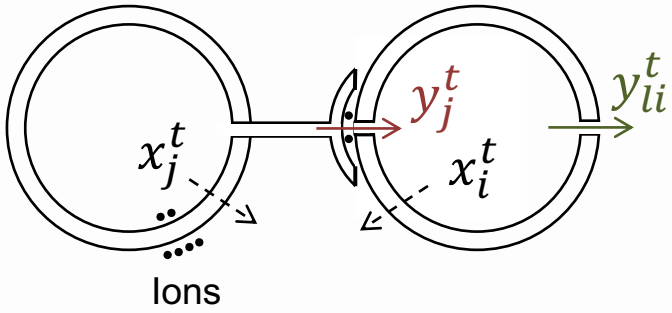
ResNets:



$$x_i^{t+1} = x_i^t + \sum_j w_{ji}^t y_j^t$$

$$y_j^t = \sigma(x_j^t, \mu_j^t)$$

CT-RNNs:



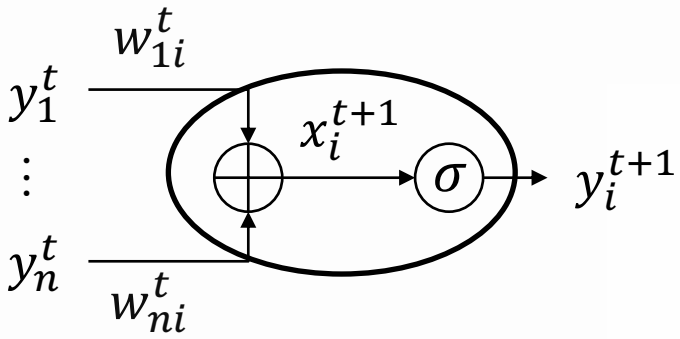
$$x_i^{t+1} = x_i^t + y_{li}^t + \sum_j w_{ji}^t y_j^t$$

$$y_{lj}^t = -w_{li} x_i^t$$

$$y_j^t = \sigma(x_j^t, \mu_j^t)$$

From Artificial to Biophysical Neurons

DNNs:



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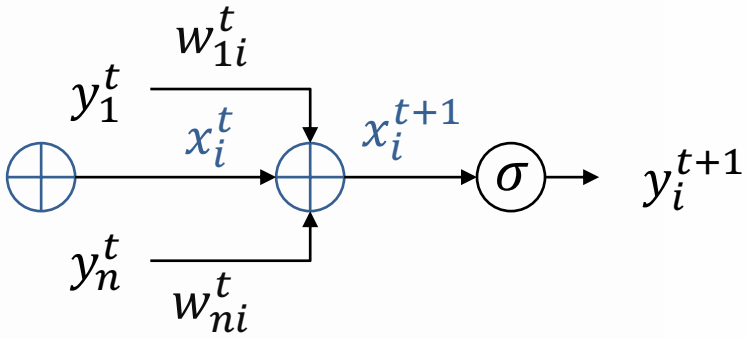

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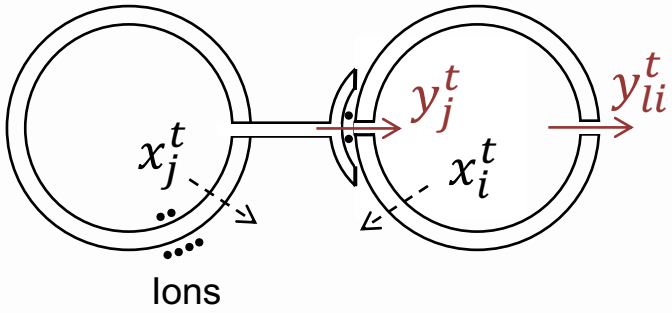
CT-RNNs:

NCPs:



$$x_i^{t+1} = x_i^t + y_{li}^t + \sum_j w_{ji}^t y_j^t$$

$$y_{lj}^t = w_{li}(e_{li} - x_i^t)$$

$$y_j^t = \sigma(x_j^t, \mu_j^t)(e_{ji} - x_i^t)$$

7th F1TENTH Autonomous Grand Prix Berlin

July 15, 2020

First Place

TUfast TUfurious

Thomas Pintaric

Mathias Lechner

Bernhard Schlögl

Axel Brunnbauer

Andreas Brandstätter

IFAC
INTERNATIONAL FEDERATION OF AUTOMATIC CONTROL

IFAC 2020 GERMANY

IFAC World Congress 2020
Competitions Chair

TU WIEN

Cyber-Physical-Systems Group

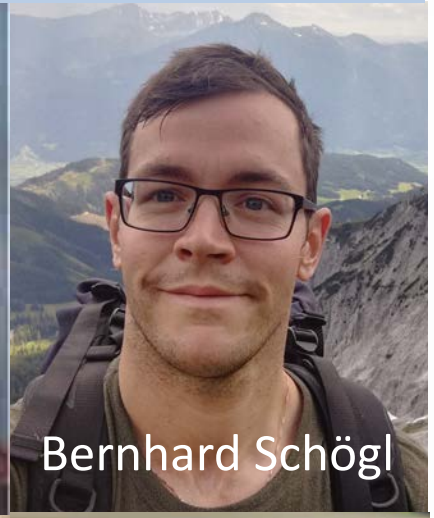
IFAC World Congress, Berlin Grand PRX

Virtual Autonomous Racing

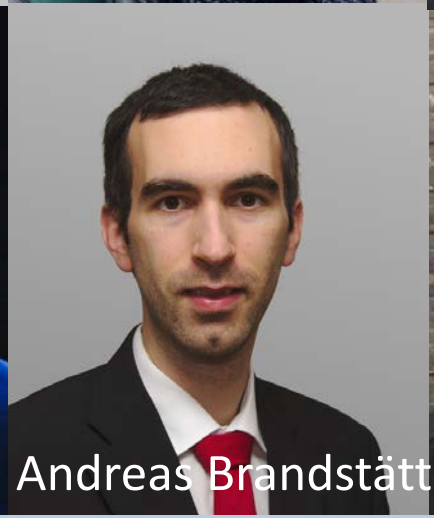

Thomas Pintaric


Mathias Lechner


Axel Brunnbauer


Bernhard Schögl


Ramin Hasani


Andreas Brandstätter


Radu Grosu


F1Tenth Racing Car

TUW Winner Team: TUfast TUfurious