A Neural Oscillator for Position Controlled Joints

Independent Study

Sayantan Auddy

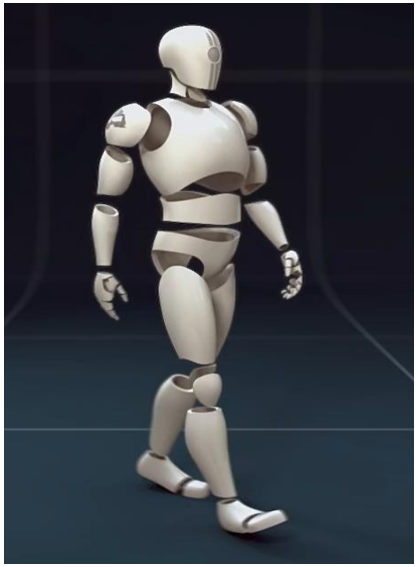
Advisor – Dr. Sven Magg

http://www.informatik.uni-hamburg.de/WTM/

Motivation

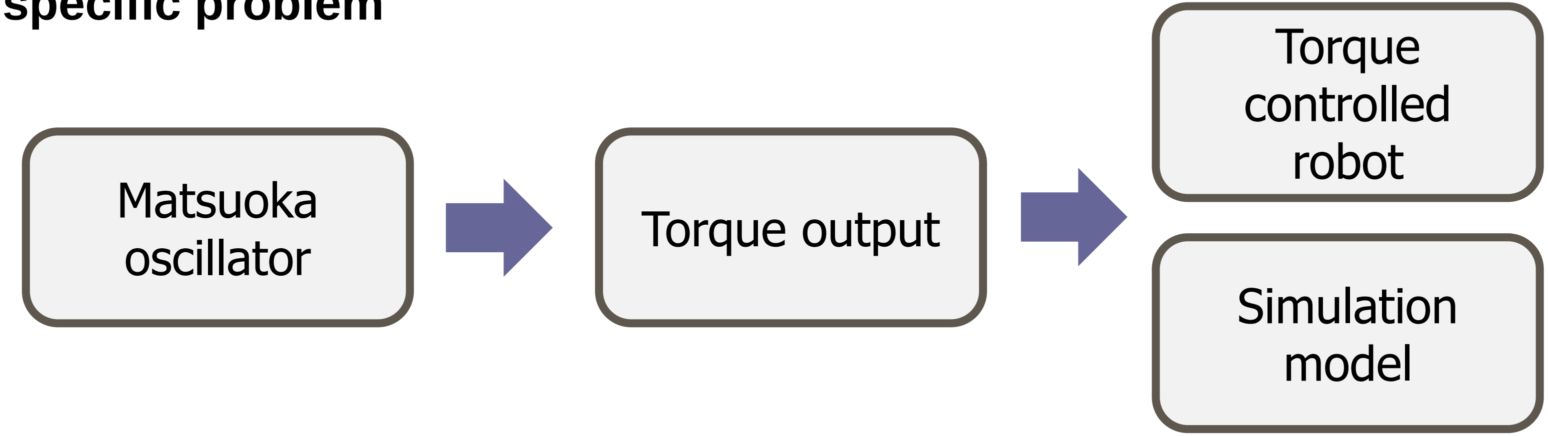
The big picture

[https://youtu.be/_kzgk4Rnpqc]



[https://vimeo.com/59197431]

The specific problem

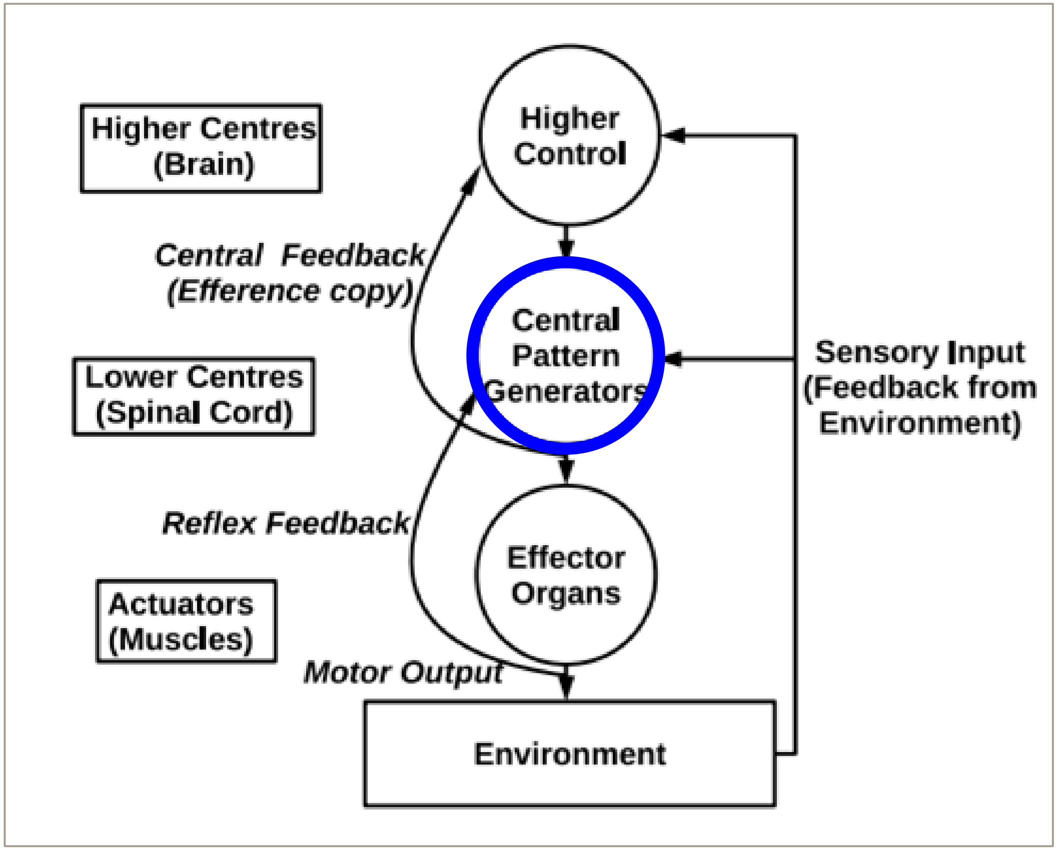


Outline

- Biological background
- Matsuoka oscillator
- Joint control using the Matsuoka oscillator
- Coupled oscillators
- Future work (master thesis spot talk)

Biological Background

- Neural Circuits (CPG) exist in the spinal cord
- Rhythmic patterns produced without rhythmic input
- Sensory feedback used for modulation

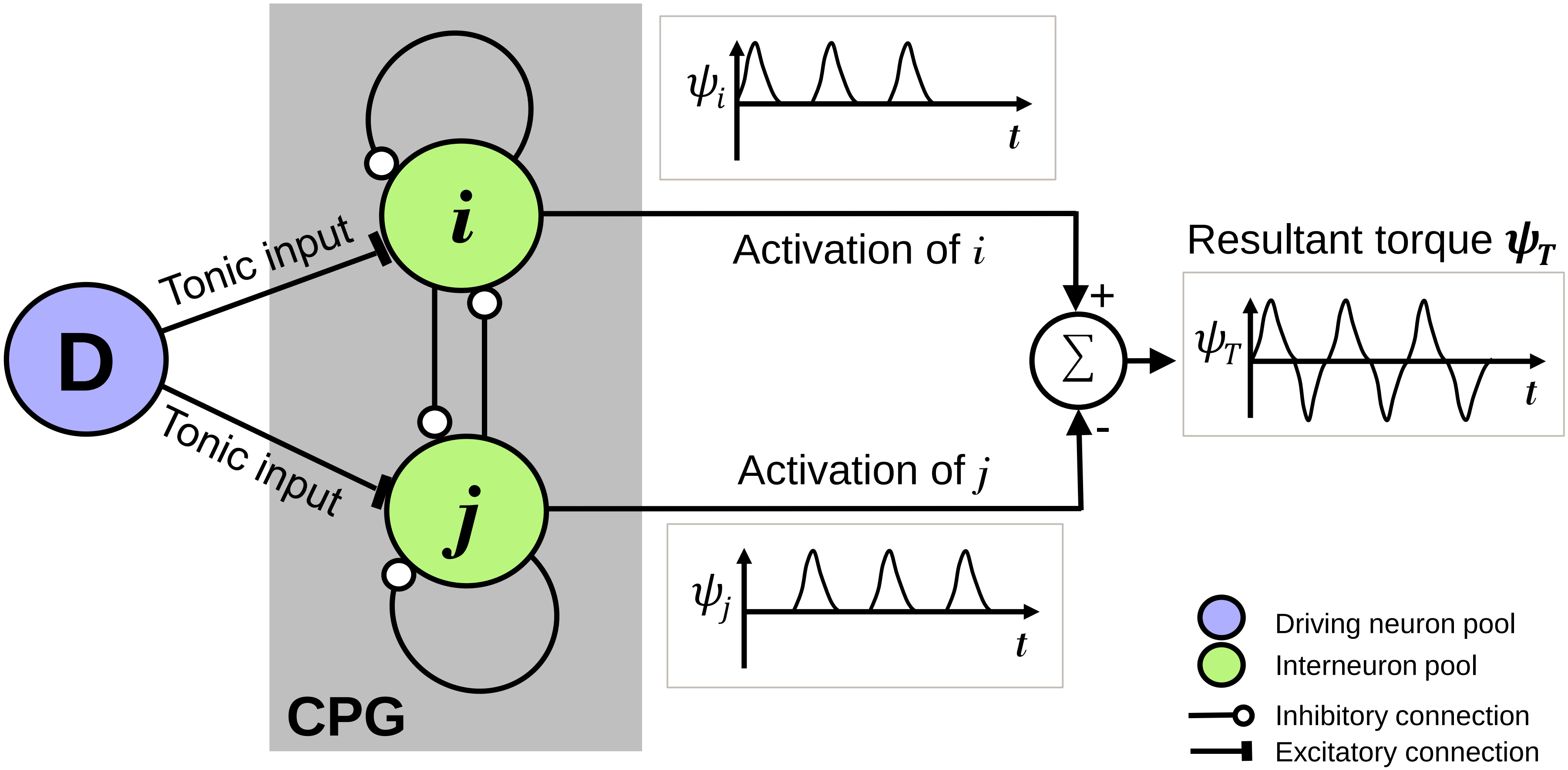


Neural components of motor systems

[Shepherd, 1994]

Half-center neuron model

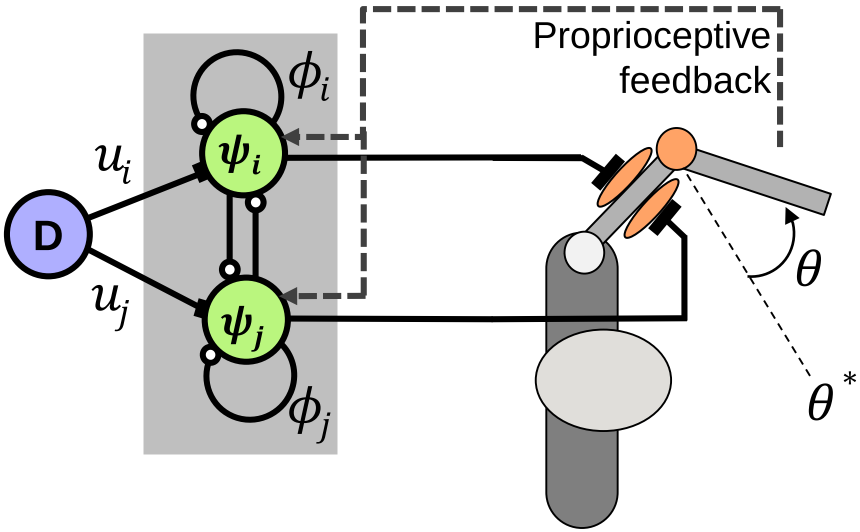
- Proposed by Brown to explain movements of a decerebrated cat
- Self and mutual inhibition leads to switching of activity [Brown, 1914]



Matsuoka Oscillator

- Mathematical model of neural rhythm generators
- Based on a piece-wise linear set differential equations

[Matsuoka, 1985, 1987]
[Ronsse, 2009]



Matsuoka equations **Feedback**

$$t_1\dot{\psi}_i = -\psi_i - \beta\phi_i - \eta[\psi_j]^+ - \sigma[\ (\theta - \theta^*)] + ui$$
$$t_1\dot{\psi}_j = -\psi_j - \beta\phi_j - \eta[\psi_i]^+ - \sigma[-(\theta - \theta^*)] + uj$$

$$t_2\dot{\varphi}_i = -\varphi_i + [\psi_i]^+$$
$$t_2\dot{\varphi}_j = -\varphi_j + [\psi_j]^+$$

$$\psi_T = h_\psi([\psi_i]^+ - [\psi_j]^+)$$

$$[\cdot]^+ = \max(0,\cdot)$$

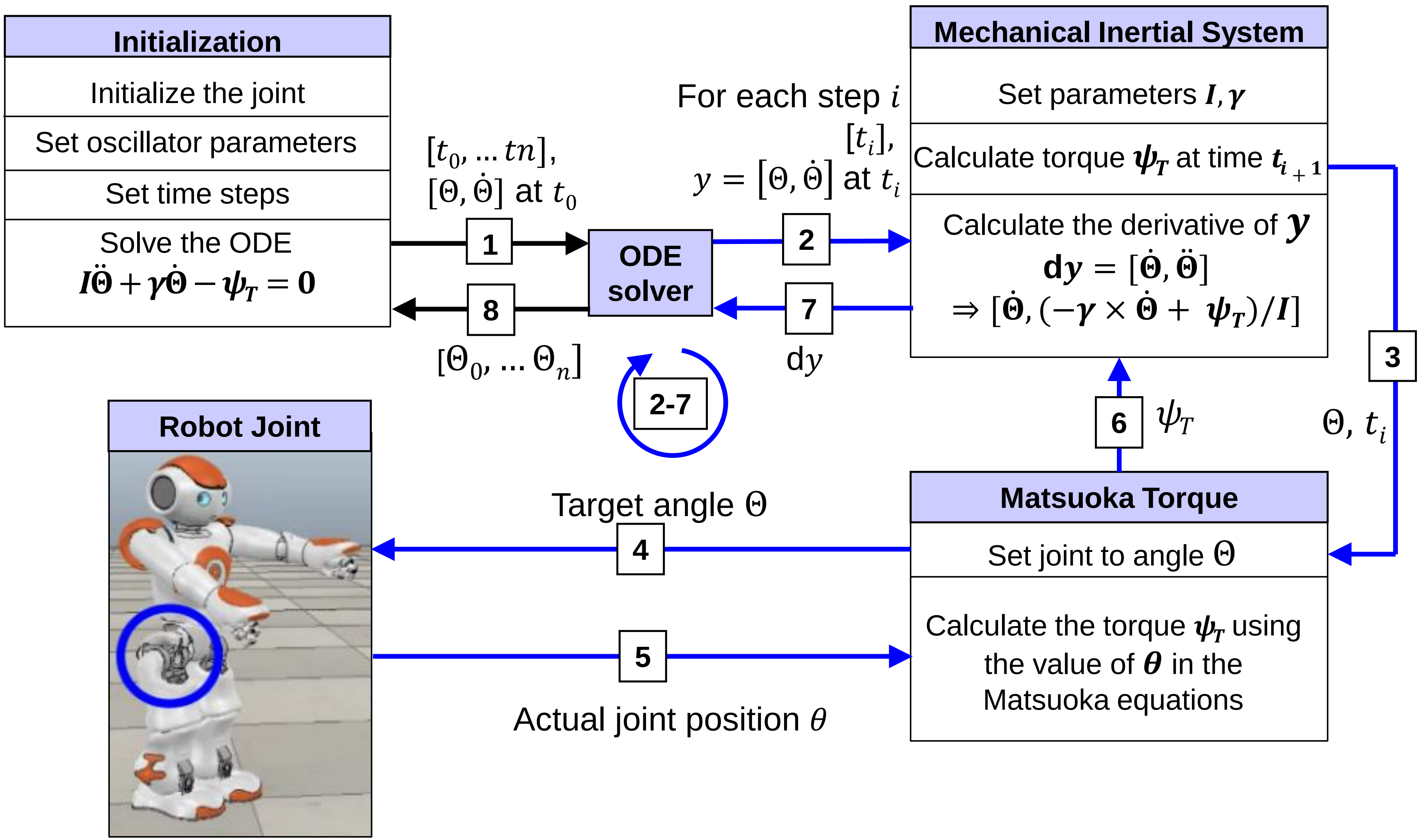
Simple inertial system

$$I\ddot{\Theta} = \psi_T - \gamma\dot{\Theta}$$
$$\Rightarrow I\ddot{\Theta} + \gamma\dot{\Theta} - \psi_T = 0$$

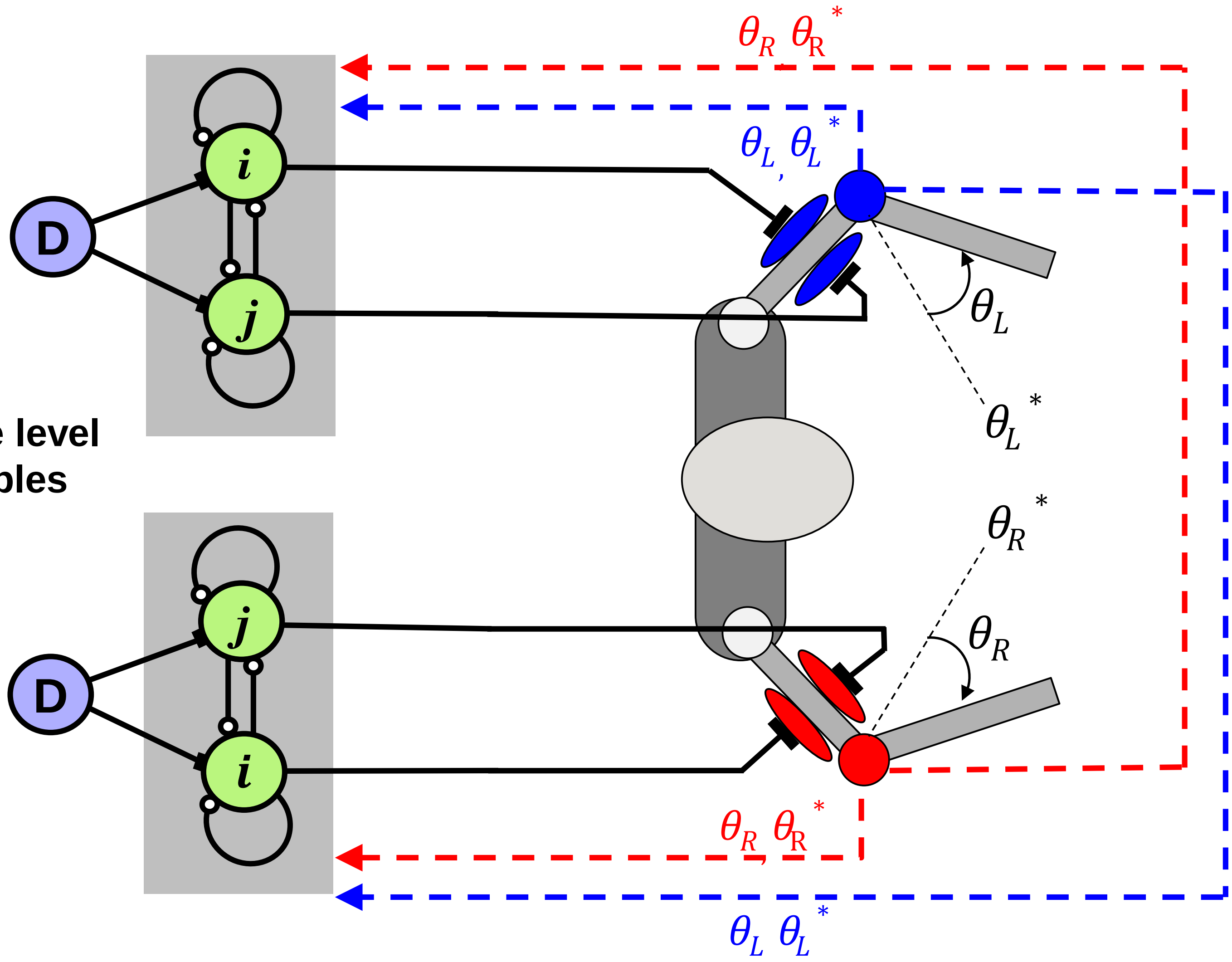
[Ronsse, 2009]

$\psi_i,\ \psi_j$: Activation of i and j
$\phi_i,\ \phi_j$: Self inhibition of i and j
u_i, u_j : Tonic inputs
$\theta,\ \theta^*$: Angular position and reference position
ψ_T : Torque applied to the joint

Proposed Joint Control Technique



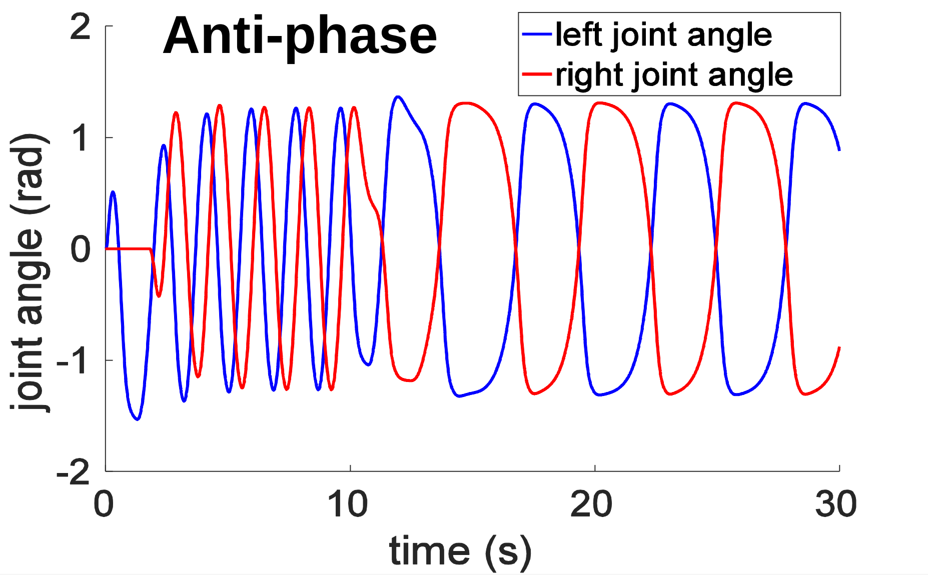
Coupling of oscillators

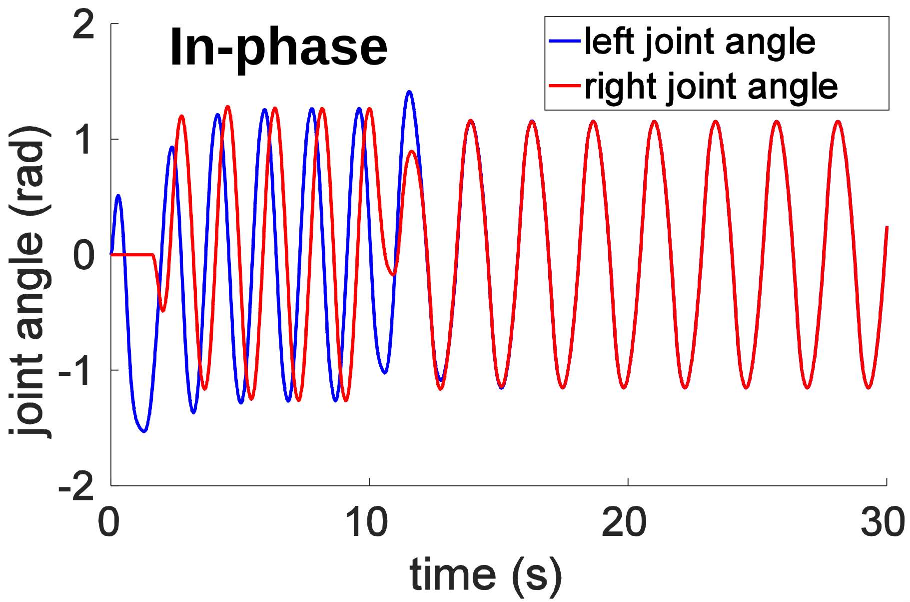


Coupling at the level of output variables

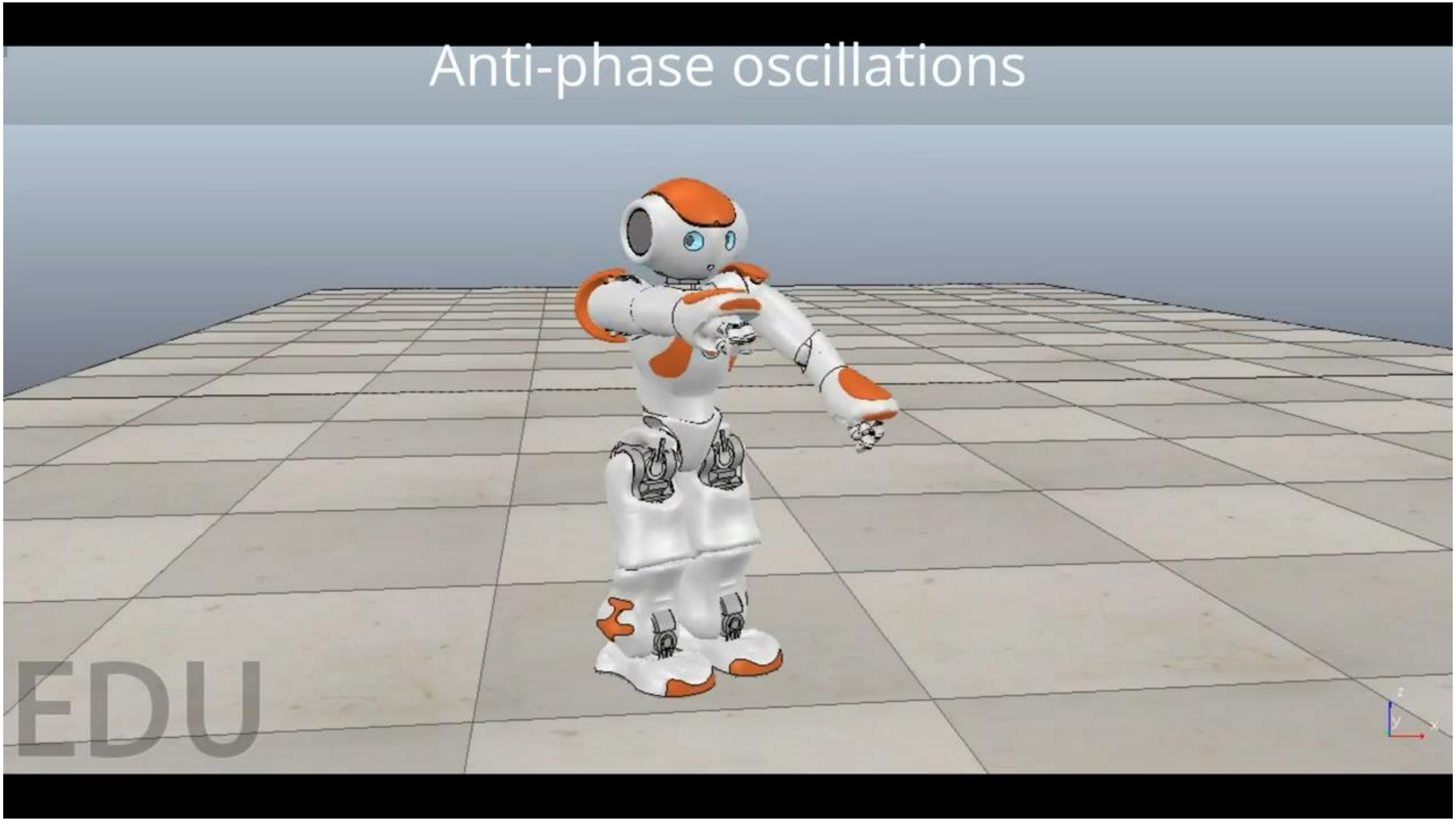
[Ronsse, 2009]

Anti-phase / in-phase oscillations





Joint Control Demonstration



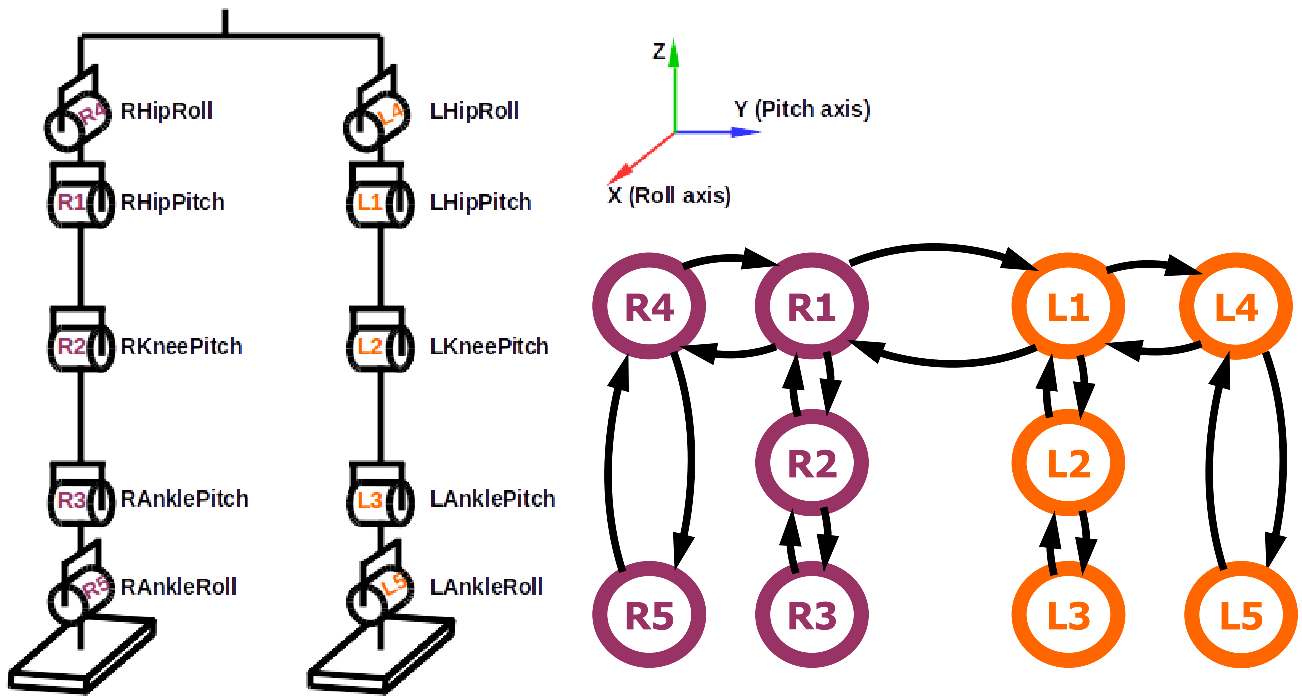
Conclusion

- Neural oscillators – bio-inspired joint control
- Use of Matsuoka oscillator limited to torque controlled robots
- Presented joint control technique adapts Matsuoka oscillator to position controlled robots
- Can serve as a base for a framework of biped locomotion

Future Work

- Development of a bio-inspired framework for walking
  - Can be implemented on any position controlled robot
  - Uses Matsuoka oscillators for controlling joints
  - Balance maintained using a neural network based controller

Neural oscillator network



Neural oscillator network controlling joints for walking

Adapted from [Kieboom, 2009]

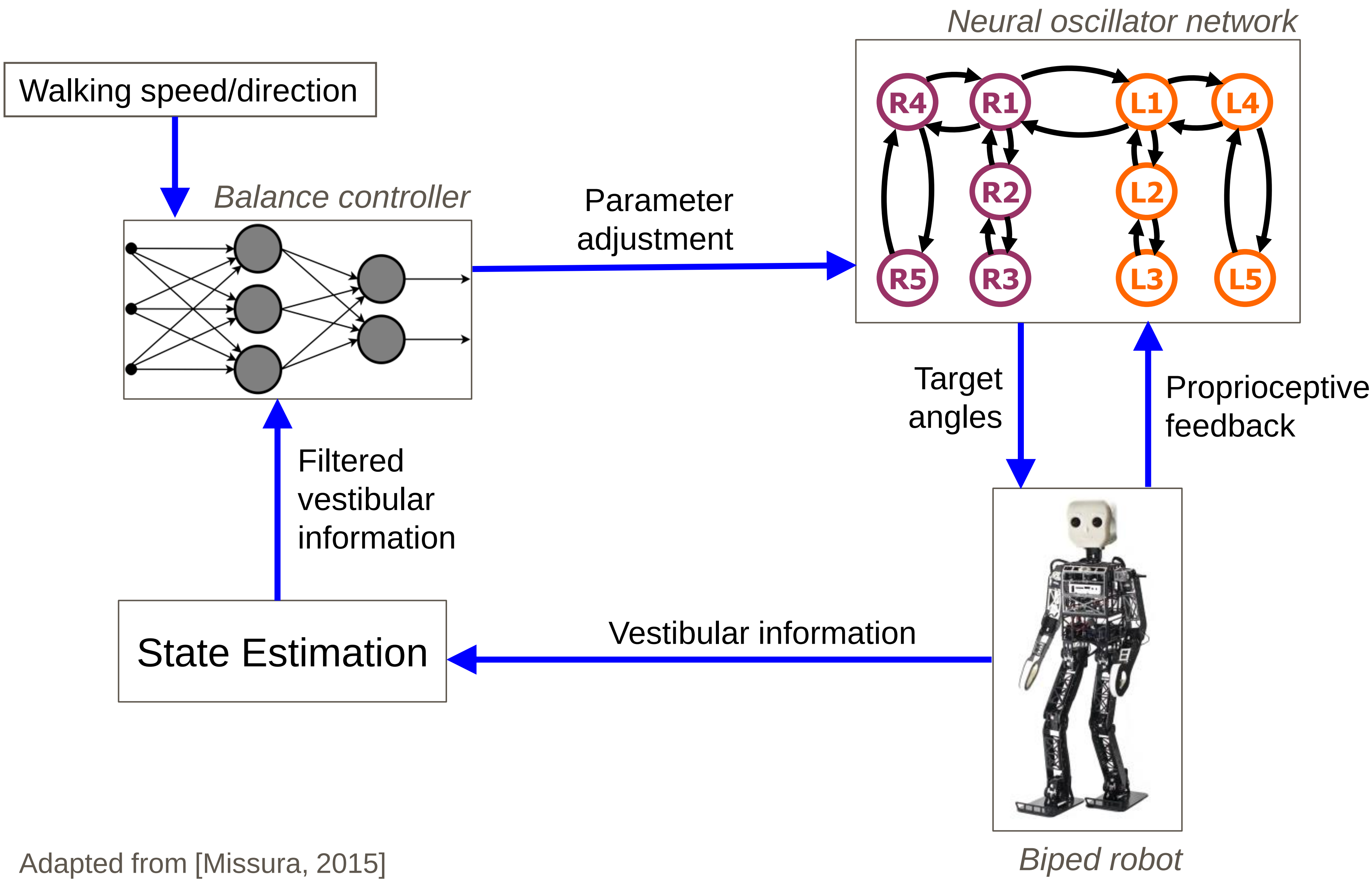
+

PSO

Optimization of oscillator parameters using PSO variants (high dimensional problem spaces)

[Pant, 2007]

Balance Controller

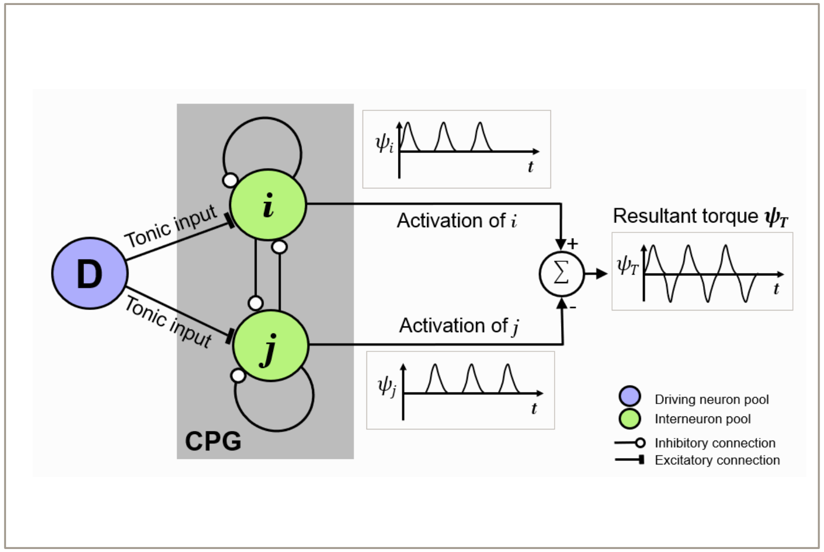


Adapted from [Missura, 2015]

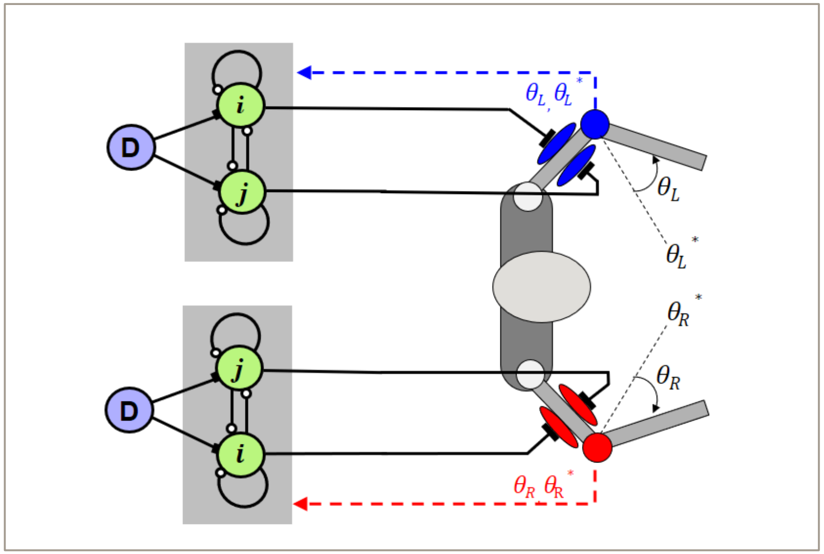
Literature

- **[Brown, 1914]** T G Brown. On the nature of the fundamental activity of the nervous centres. The Journal of Physiology, 1914.
- **[Kieboom, 2009]** J V D Kieboom. Biped Locomotion and Stability - A Practical Approach. Master's thesis, University of Groningen, 2009.
- **[Matsuoka, 1985]** K Matsuoka. Sustained oscillations generated by mutually inhibiting neurons with adaptation. Biological cybernetics, 1985.
- **[Matsuoka, 1987]** K Matsuoka. Mechanisms of frequency and pattern control in the neural rhythm generators. Biological Cybernetics, 1987.
- **[Missura, 2015]** M Missura and S Behnke. Gradient-driven online learning of bipedal push recovery. IROS, 2015.
- **[Pant, 2007]** M Pant, T Radha, and V P Singh. A Simple Diversity Guided Particle Swarm Optimization. In IEEE Congress on Evolutionary Computation, 2007.
- **[Ronsse, 2009]** R Ronsse, D Sternad, and P Lefevre. A computational model for rhythmic and discrete movements in uni-and bimanual coordination. Neural computation, 2009.
- **[Shepherd, 1994]** Gordon M. Shepherd. Neurobiology. Oxford University Press, 1994.

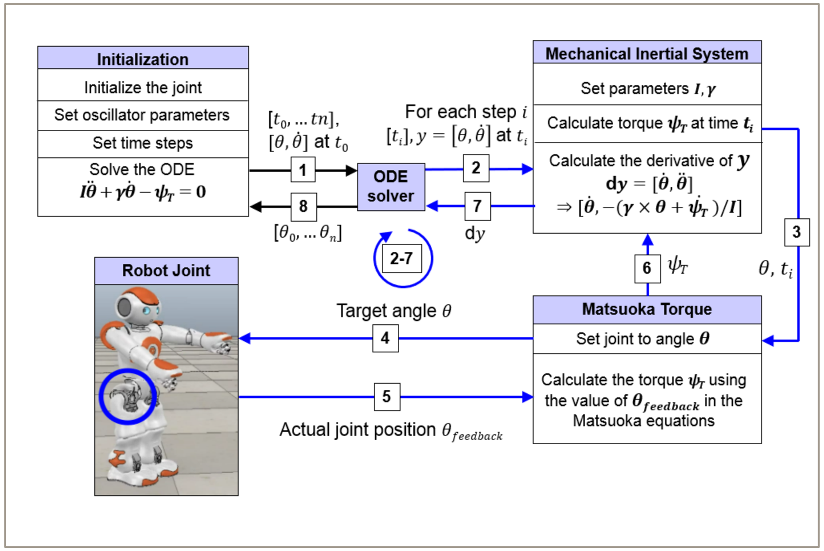
Thank you



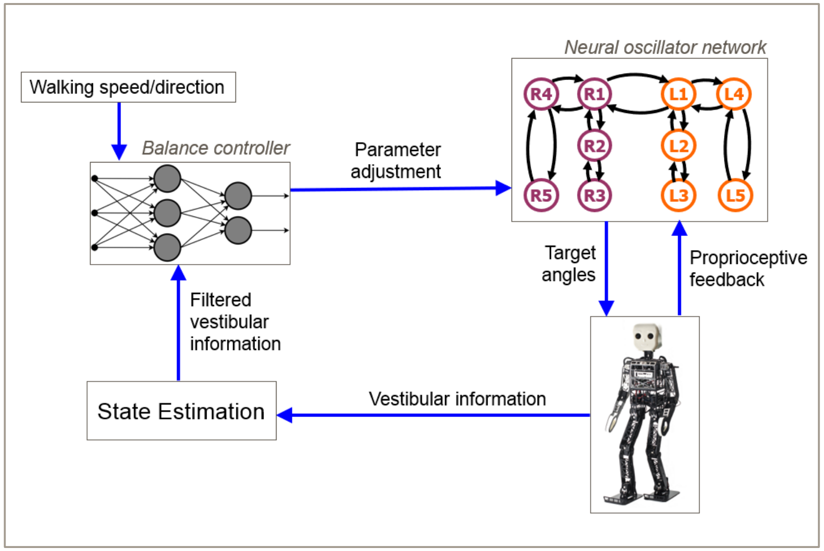
Tonic input
Tonic input
D
i
j
CPG
Activation of i
Activation of j
Resultant torque ψ_T
Driving neuron pool
Interneuron pool
Inhibitory connection
Excitatory connection



D
i
j
θ_L, θ_L^*
θ_L
θ_L^*
θ_R^*
θ_R
θ_R, θ_R^*



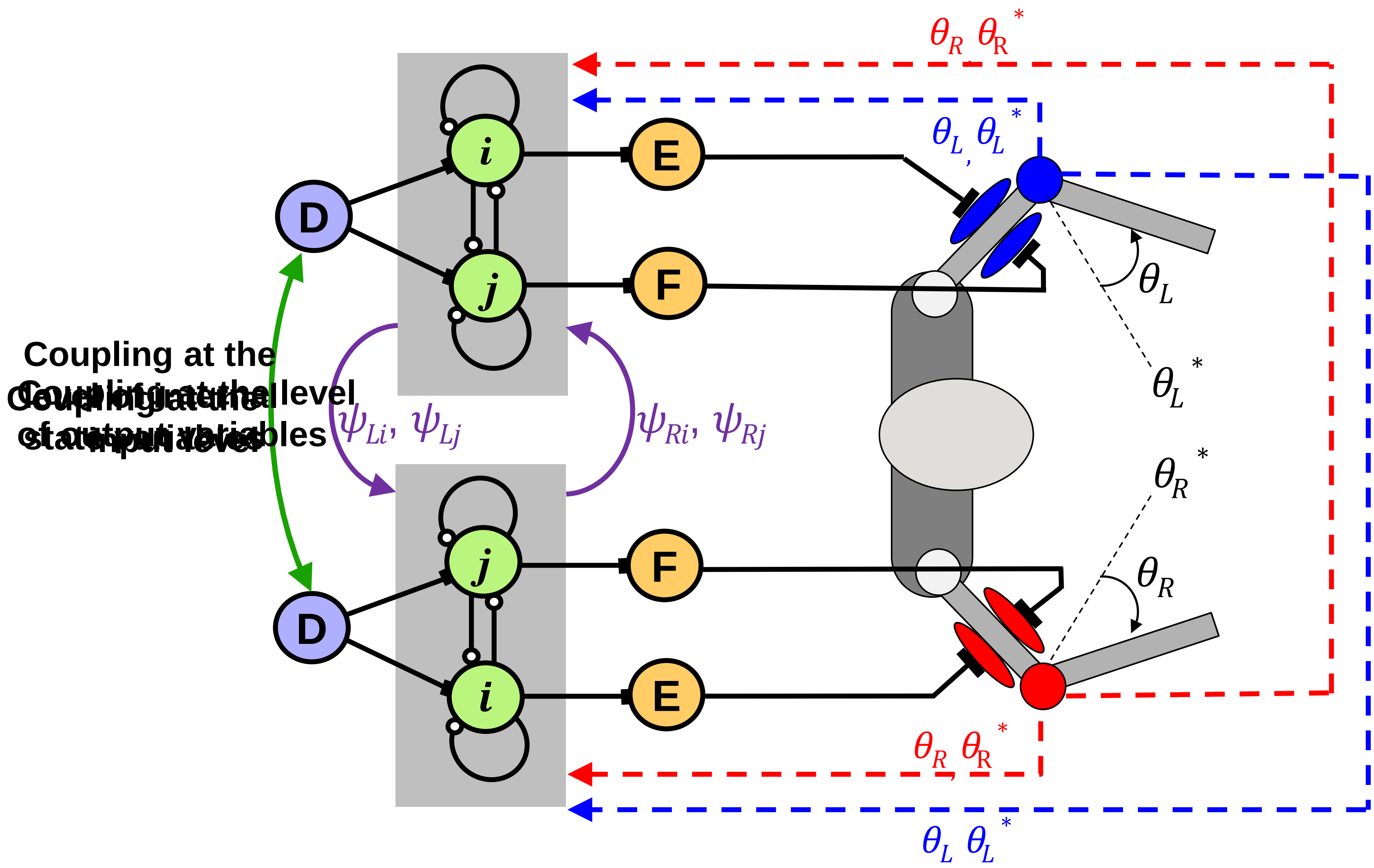
Initialization
Initialize the joint
Set oscillator parameters
Set time steps
Solve the ODE
$I\ddot{\theta} + \gamma\dot{\theta} - \psi_T = 0$
$[t_0, \dots tn]$,
$[\theta, \dot{\theta}]$ at t_0
For each step i
$[t_i], y = [\theta, \dot{\theta}]$ at t_i
ODE solver
$[\theta_0, \dots \theta_n]$
dy
2-7
Mechanical Inertial System
Set parameters I, γ
Calculate torque ψ_T at time t_i
Calculate the derivative of y
$dy = [\dot{\theta}, \ddot{\theta}]$
$\Rightarrow [\dot{\theta}, -(\gamma \times \theta + \dot{\psi}_T)/I]$
ψ_T
θ, t_i
Robot Joint
Target angle θ
Matsuoka Torque
Set joint to angle θ
Calculate the torque ψ_T using the value of $\theta_{feedback}$ in the Matsuoka equations
Actual joint position $\theta_{feedback}$



Walking speed/direction
Balance controller
Parameter adjustment
Neural oscillator network
R4
R1
L1
L4
R2
L2
R5
R3
L3
L5
Target angles
Proprioceptive feedback
Filtered vestibular information
State Estimation
Vestibular information

Extra slides

Different Coupling Mechanisms

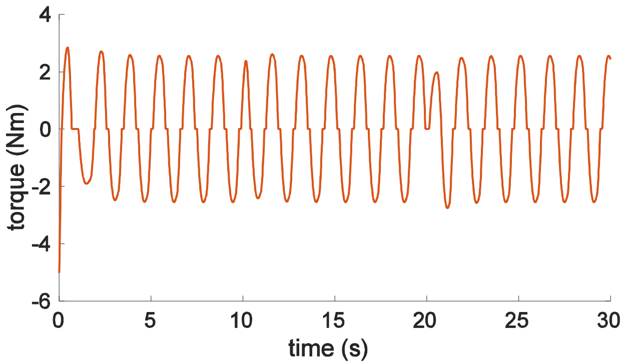


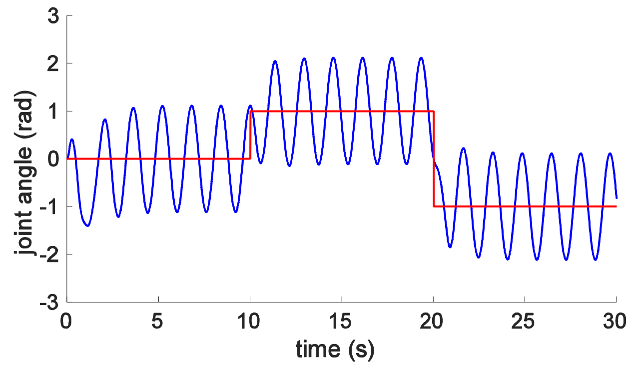
[Ronsse, 2009]

Output Pattern Modulation

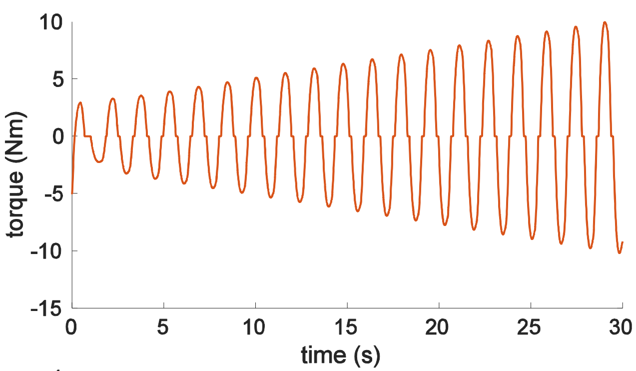
Joint torques

Joint angles -- joint angle -- reference position

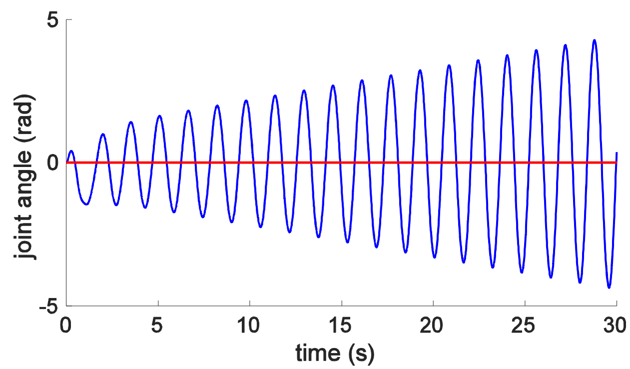




Reference angle θ^* varied (0 to 1 to -1 radians)



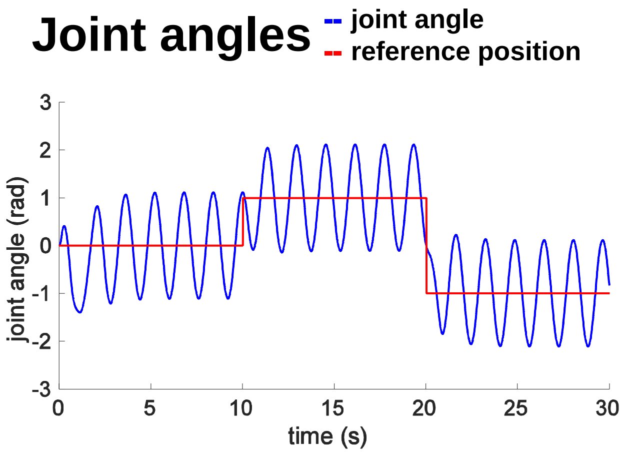
4



Tonic inputs u_i, u_j varied from 1.0 to 4.0

Helpful Properties

- Stable limit cycle properties
- Entrainment
- Easy to modulate waveforms
- Any number of oscillators can be coupled together



Reference angle θ^* varied (0 to 1 to -1 radians)

Stable Attractors