Movement Classification for Versatile CPG Control

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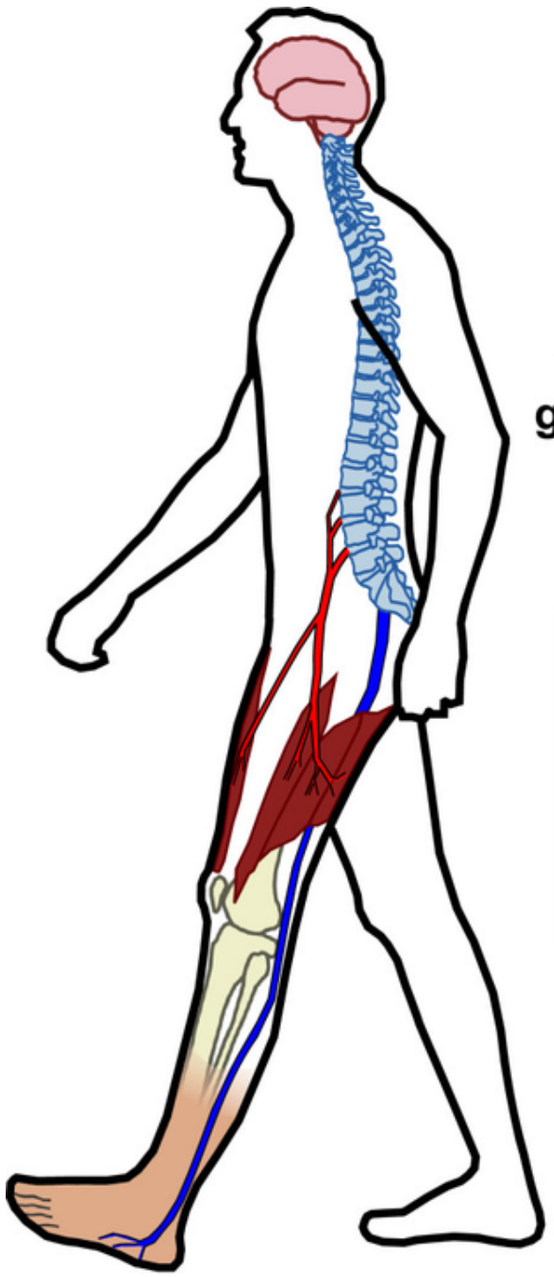
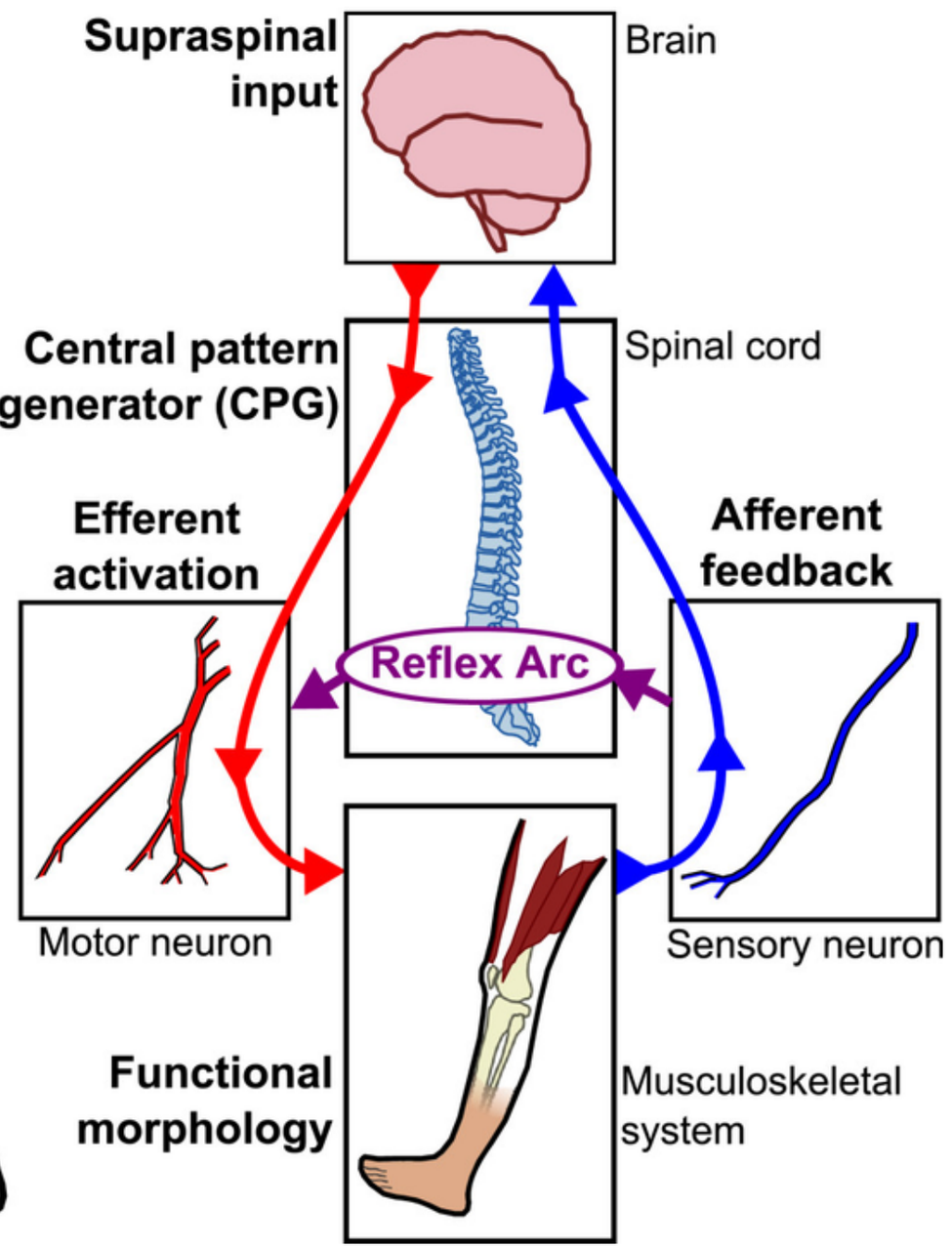
Motor Control

- Brain sends signal
- CPG generates movement
  - modulated by sensory information

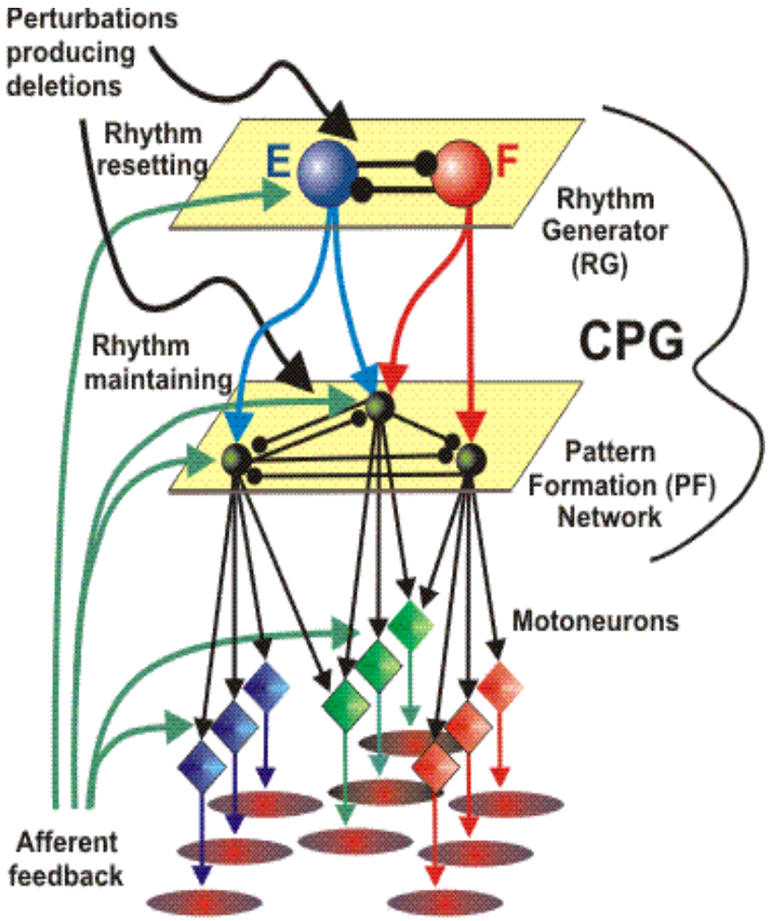




[Tucker et al, 2015]

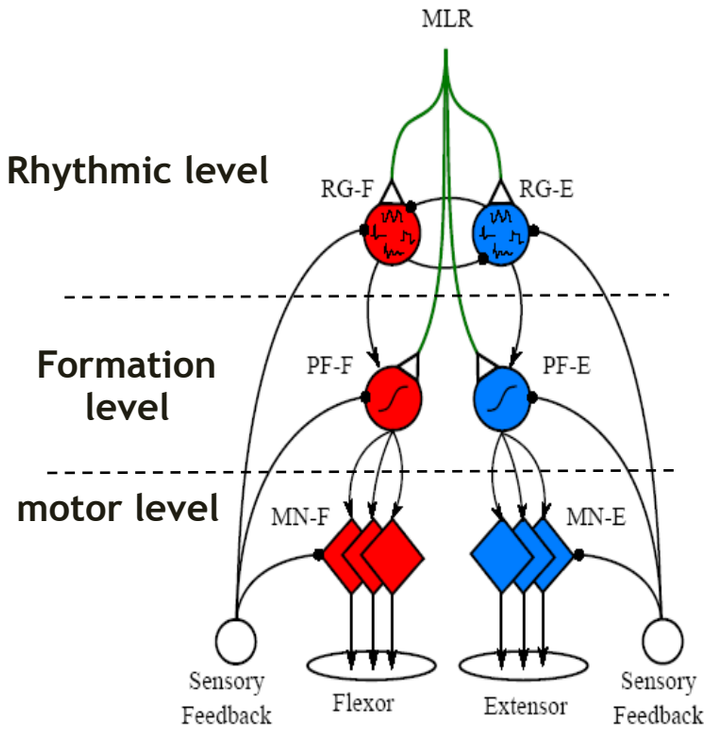
CPG Models

Biological model for CPG



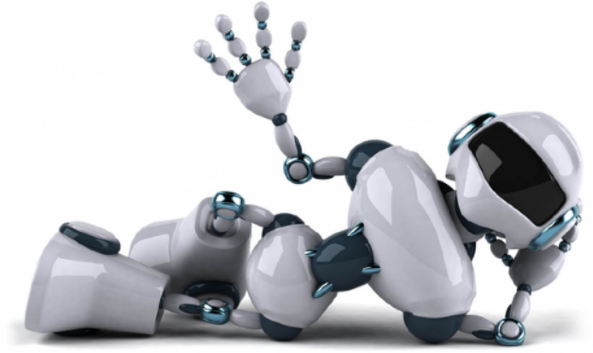
[McCrea and Rybak, 2008]

Computational model for CPG



[Amrollah and Hénaff, 2010], [Nassour et al, 2014]

What About Robots?



- Adaptive behaviour in human-robot interactions
  - Adequate response given a context and interaction partner
  - Emergence of interpersonal movements coordination
    - Emergence of social synchrony

- Bio-inspired plastic controllers that can adapt for a more natural interaction
  - CPG based on non-linear dynamic oscillators for natural synchronisation
  - Hebbian plasticity to learn interaction parameters

CPG Architecture

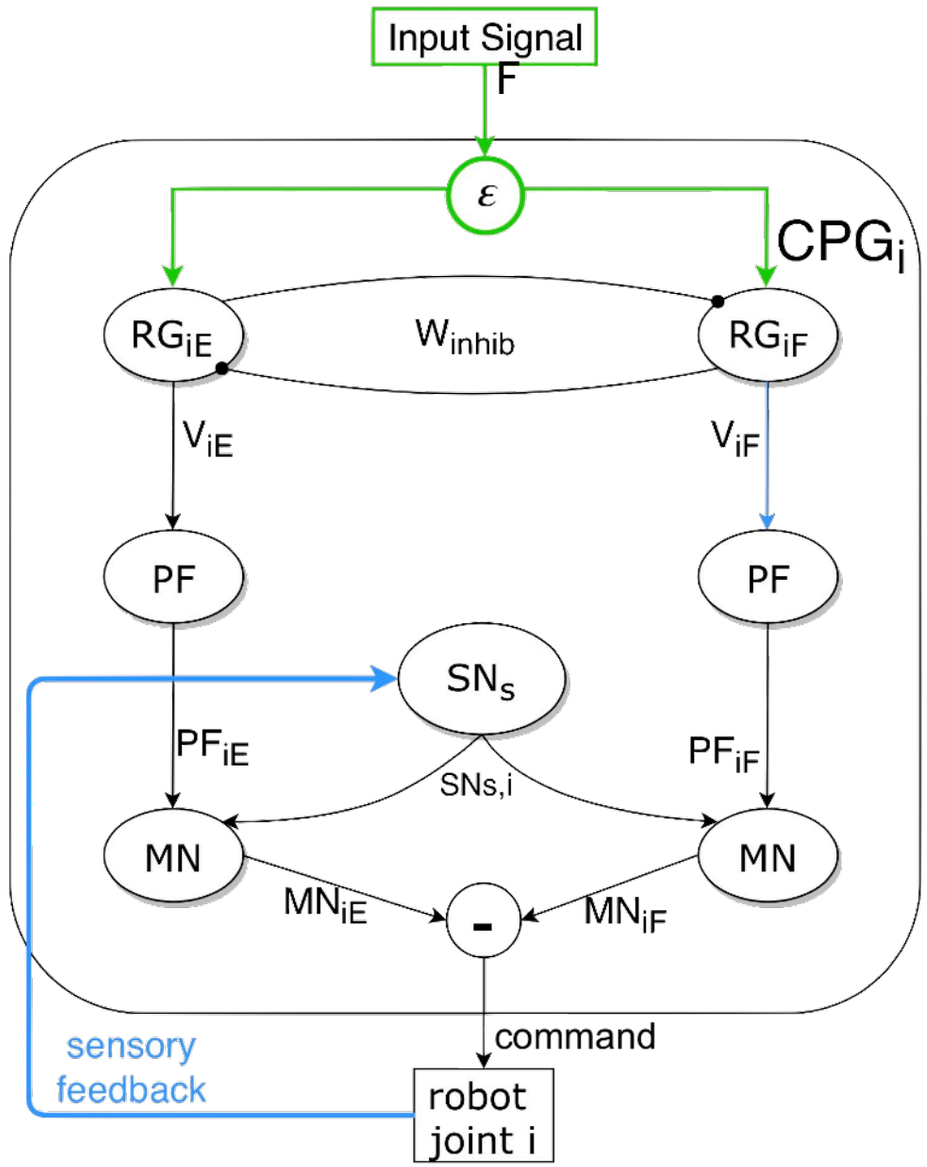
- **Rhythmic generator cells RG (Rowat-Selverston neurons):**

$$\dot{V} = y + \epsilon F$$

$$\dot{y} = \left(\sigma_f - \frac{\tau_m}{\tau_s} - 1 - \sigma_f \tanh^2\left(\frac{\sigma_f}{A_f}V\right)\right)\frac{y}{\tau_m} - \frac{1+\sigma_s}{\tau_s\tau_m}V + \frac{A_f}{\tau_s\tau_m}\tanh\left(\frac{\sigma_f V}{A_f}\right)$$

- **Interneurons (sigmoid)**
  - **Pattern Formation PF**
  - **Sensory neurons SN**
  - **Motor neurons MN**

- **Learning rules:**
  - **Frequency learning for σ_S** **[Righetti et al, 2006]**
  - **Amplitude learning for A_f**
  - **Input gain learning for ϵ**



[Jouaiti, M., Caron, L., and Henaff, P. (2018). Hebbian plasticity in CPG controllers facilitates self-synchronization for human-robot handshaking, Frontiers in Neurorobotics]

Discrete VS Rhythmic

- Discrete: singularly occurring events preceded and followed by a period without motion
  - reaching
- Rhythmic: continuous and recurring periodically
  - cleaning, eggs beating
- Movements can be composed of both
  - piano playing, sewing
- Or a concatenation of both
  - basketball

Discrete:
The CPG behaves as a PID Controller

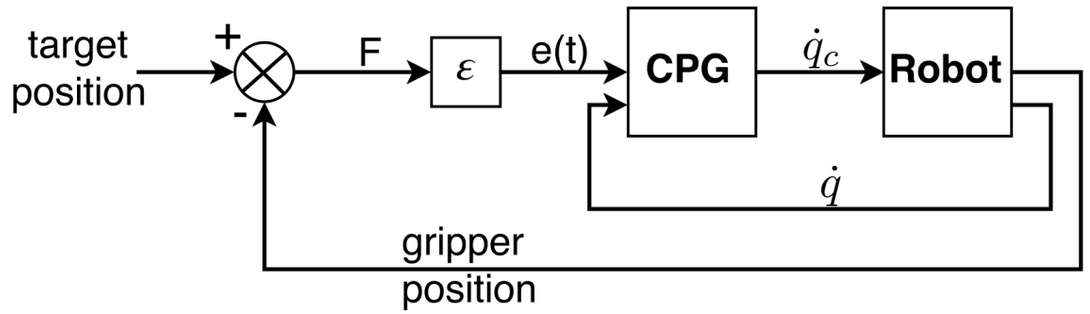
$$\dot{V} = y + \epsilon F$$

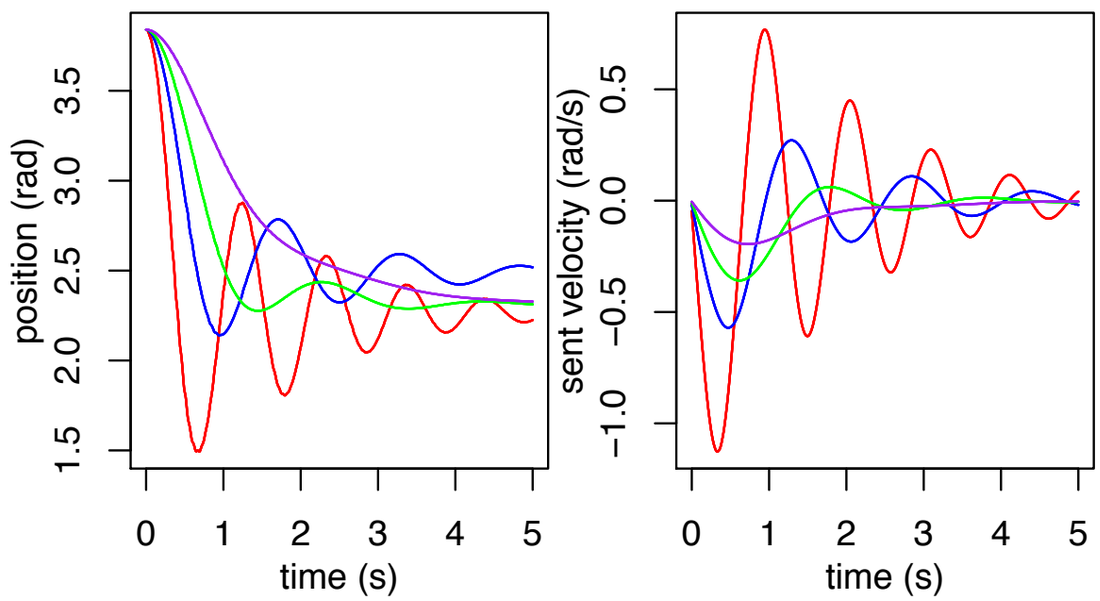
$$\ddot{V} + \frac{\tau_s + \tau_m}{\tau_s \tau_m}\dot{V} + \frac{1 + \sigma_s}{\tau_s \tau_m}V = 0$$

- Can be transformed into:

$$\dot{q} = \frac{1}{\alpha b}\left(\underbrace{ae(t) + b\int e(t)dt + \dot{e}(t)}_{P} \underbrace{-a\ddot{q}}_{D} - \dddot{q}\right)$$

- Term P is the PID part
- In term D, $\dot{q}$ represents the dynamical behaviour of the robot
- $\dddot{q}$ represents the jerk

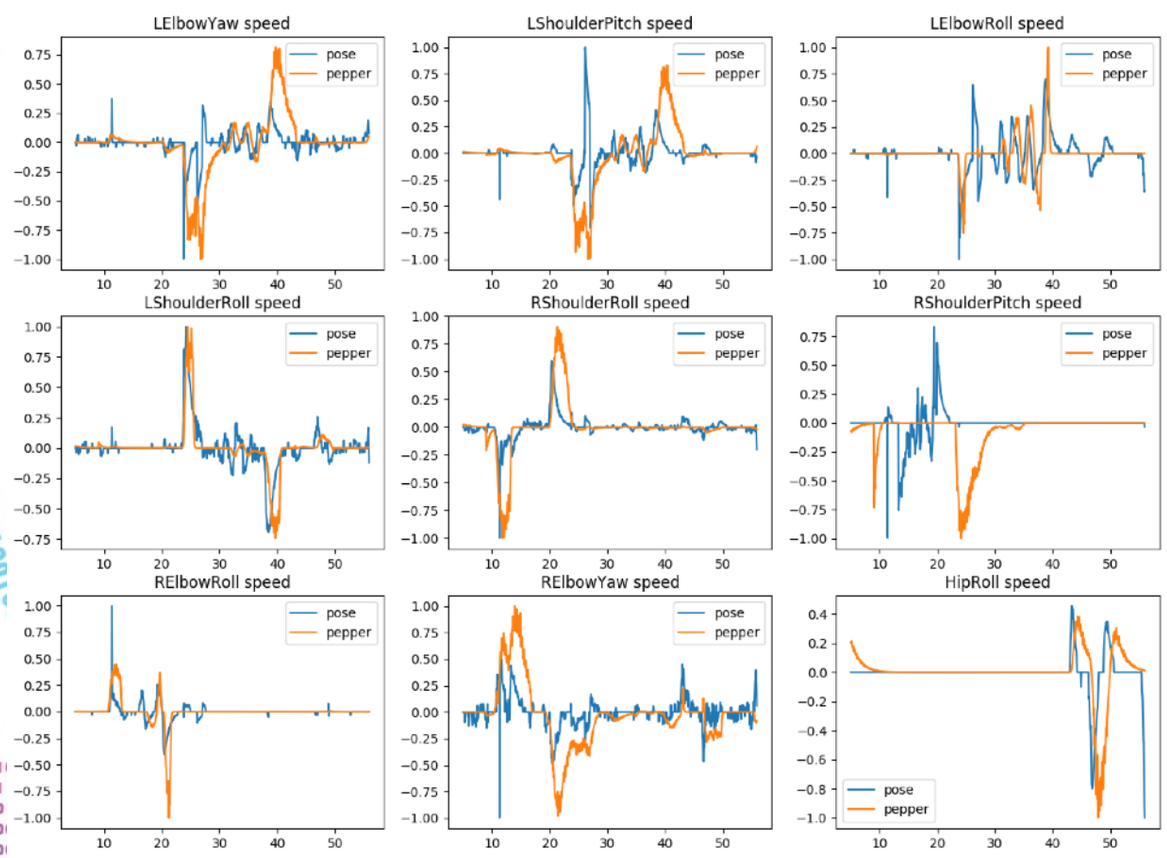


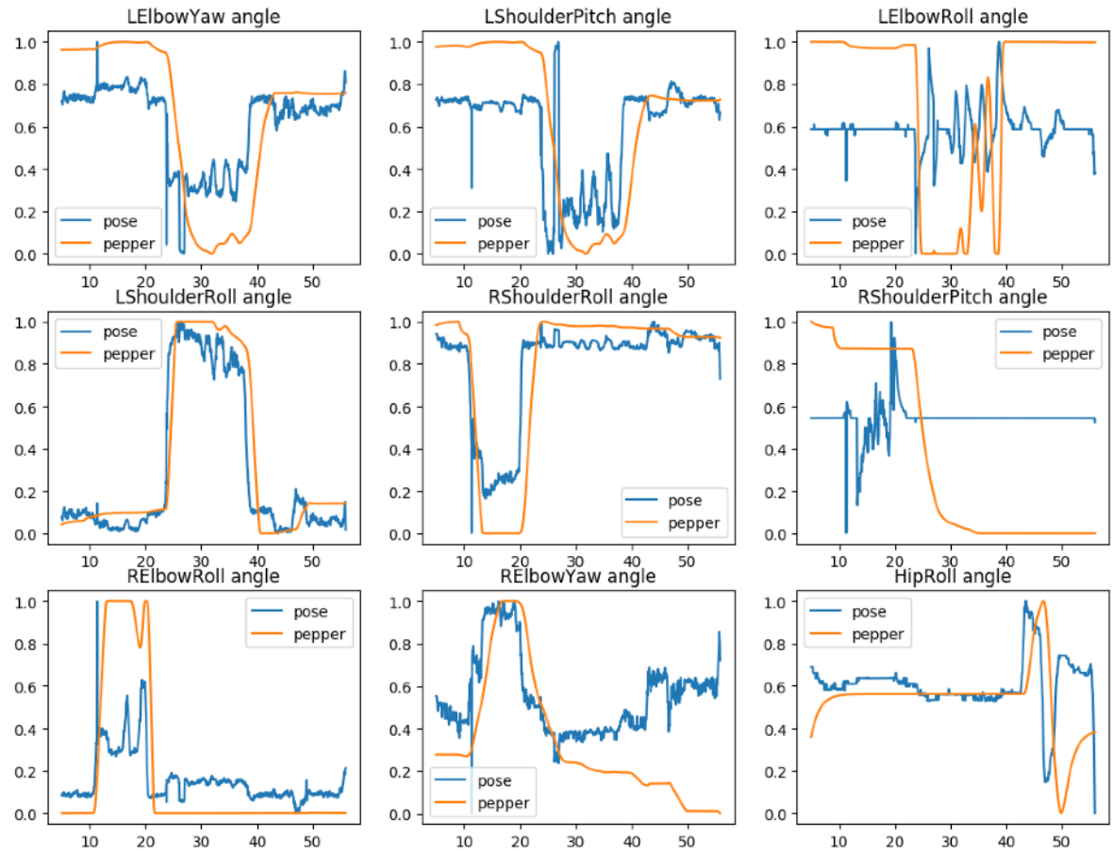


[Jouaiti, M., and Henaff, P. (2018). CPG-based Controllers can Generate Both Discrete and Rhythmic Movements, IROS]

Discrete: Motor Imitation

- 2D pose estimation
- Transformation to 3D
- angular speed for CPG input



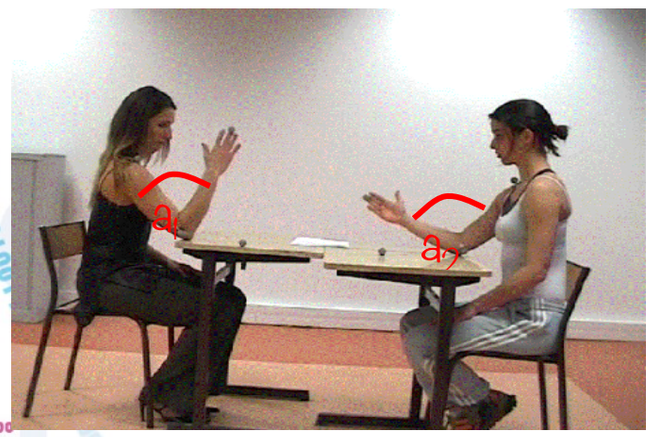


[Jouaiti, M., Descouens, N. and Henaff, P. (2019). Pose Imitation Using CPG Controllers, ICRA, in prep.]

Rhythmic Mode: Involuntary Coordination

Emergence of synchrony is so powerful that humans cannot avoid involuntary motor coordination

Compromise between motor control and interaction



An interaction is based mostly on two phenomena:

- *magnet effect*: the individual is entrained by the partner and tends to synchronise
- *maintenance effect*: struggle of the individual to retain its identity and own rhythm

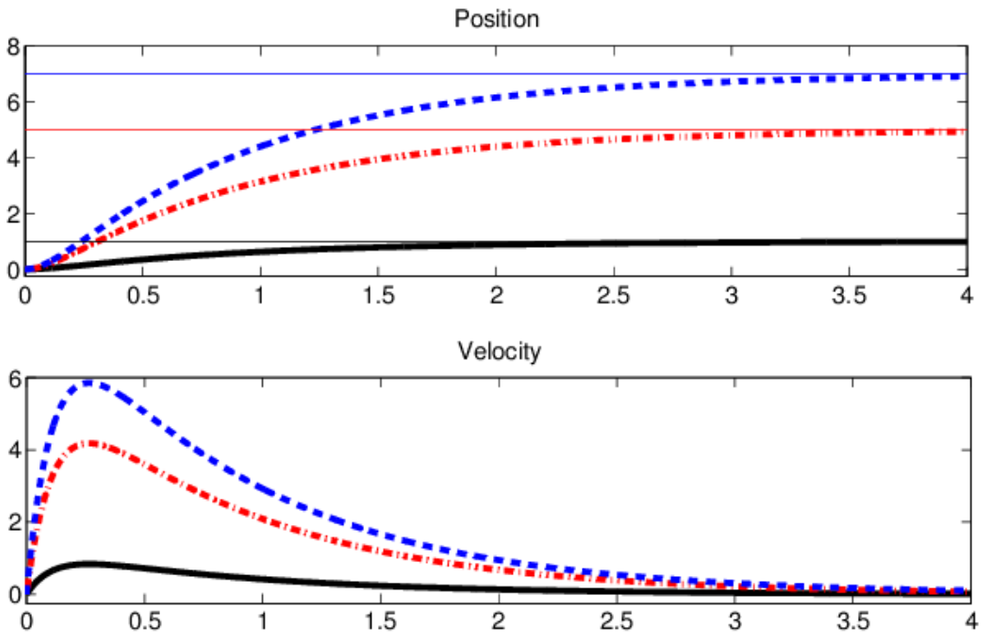
Rhythmic Mode: Motor Coordination

https://members.loria.fr/mjouaiti/files/EPIROB19_1.mp4

[Jouaiti, M., and Henaff, P. (2019). Motor Coordination Learning for Rhythmic Movements, ICDL-Epirob]

Combining Rhythmic and Discrete

- Combination of a discrete and a rhythmic pattern generator to achieve both:
  - Hopf + VITE (Degallier et al, 2011)
  - Matsuoka + VITE (Sternad et al, 2000)
- Cumbersome parameter tuning



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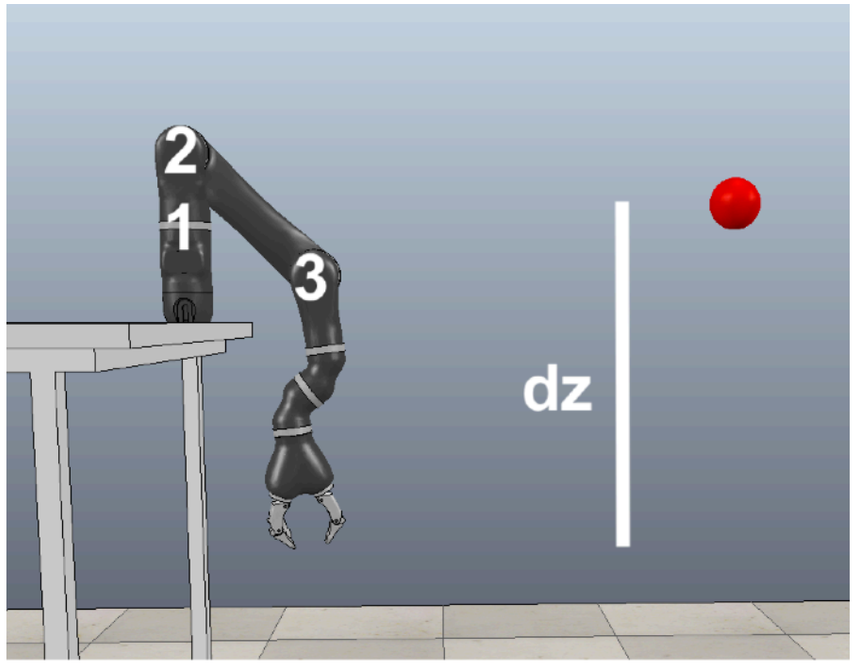
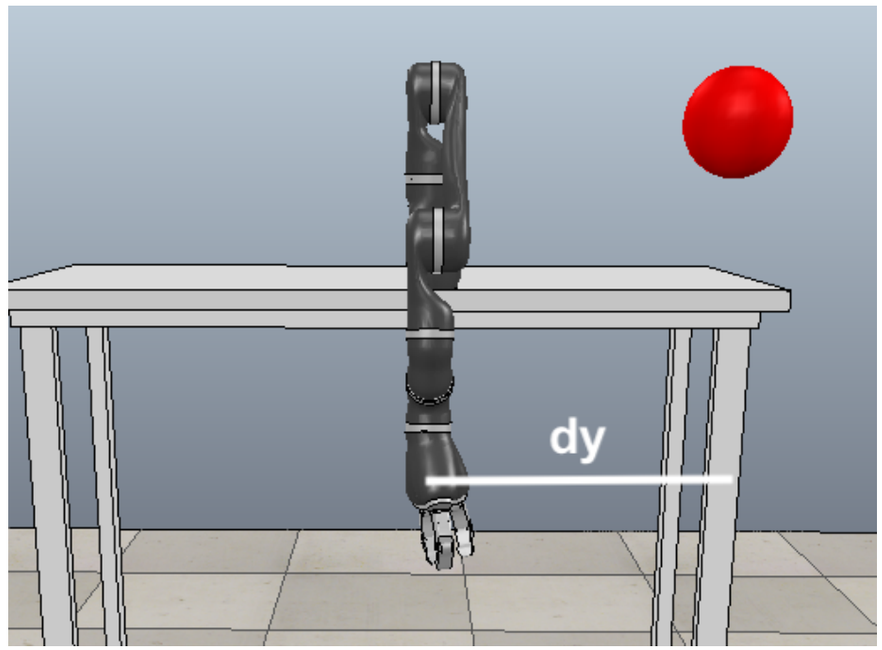
Rhythmic & Discrete: Experimental Setup

- Colour detection with OpenCV
- Distance estimation in the y and z plane
  - forward kinematic model of the robot
- Distance is the input of CPG:
  - Joints 2 and 3 reduce dz
  - Joint 1 reduces dy





[Jouaiti, M., and Henaff, P. (2018). CPG-based Controllers can Generate Both Discrete and Rhythmic Movements, IROS]

Rhythmic & Discrete: Results

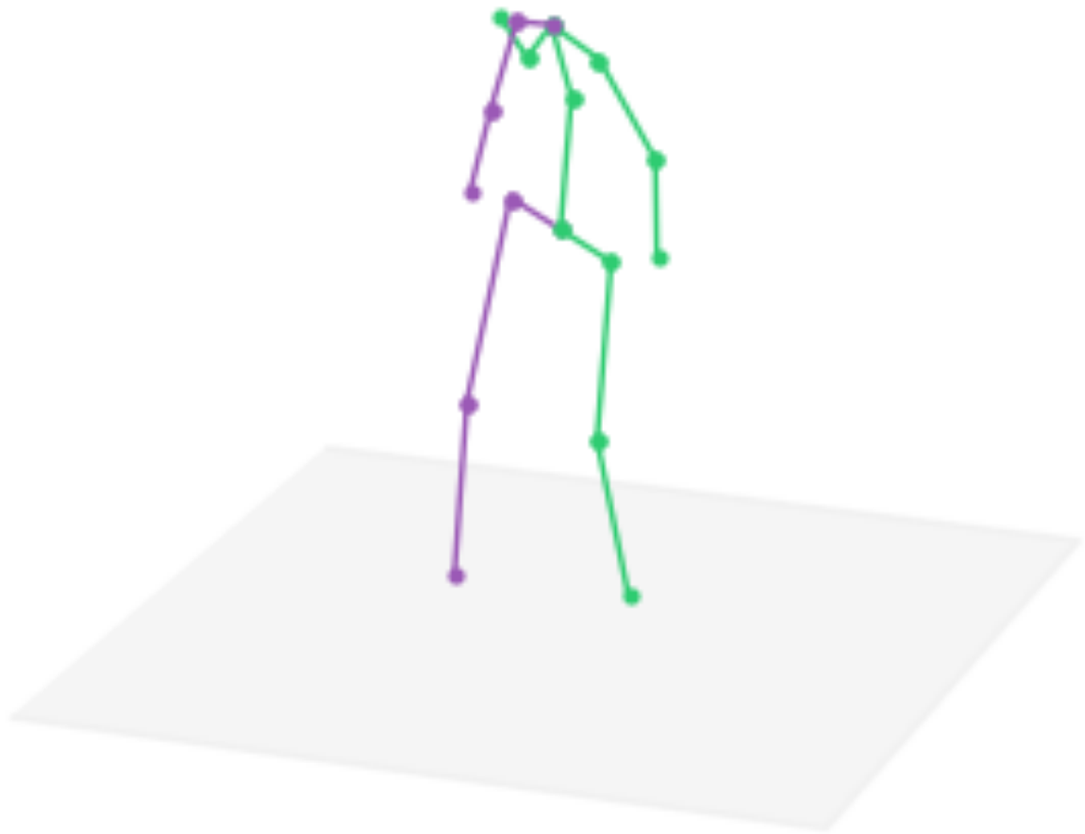
Articular phase portrait

CPG phase portrait

[Jouaiti, M., and Henaff, P. (2018). CPG-based Controllers can Generate Both Discrete and Rhythmic Movements, IROS]

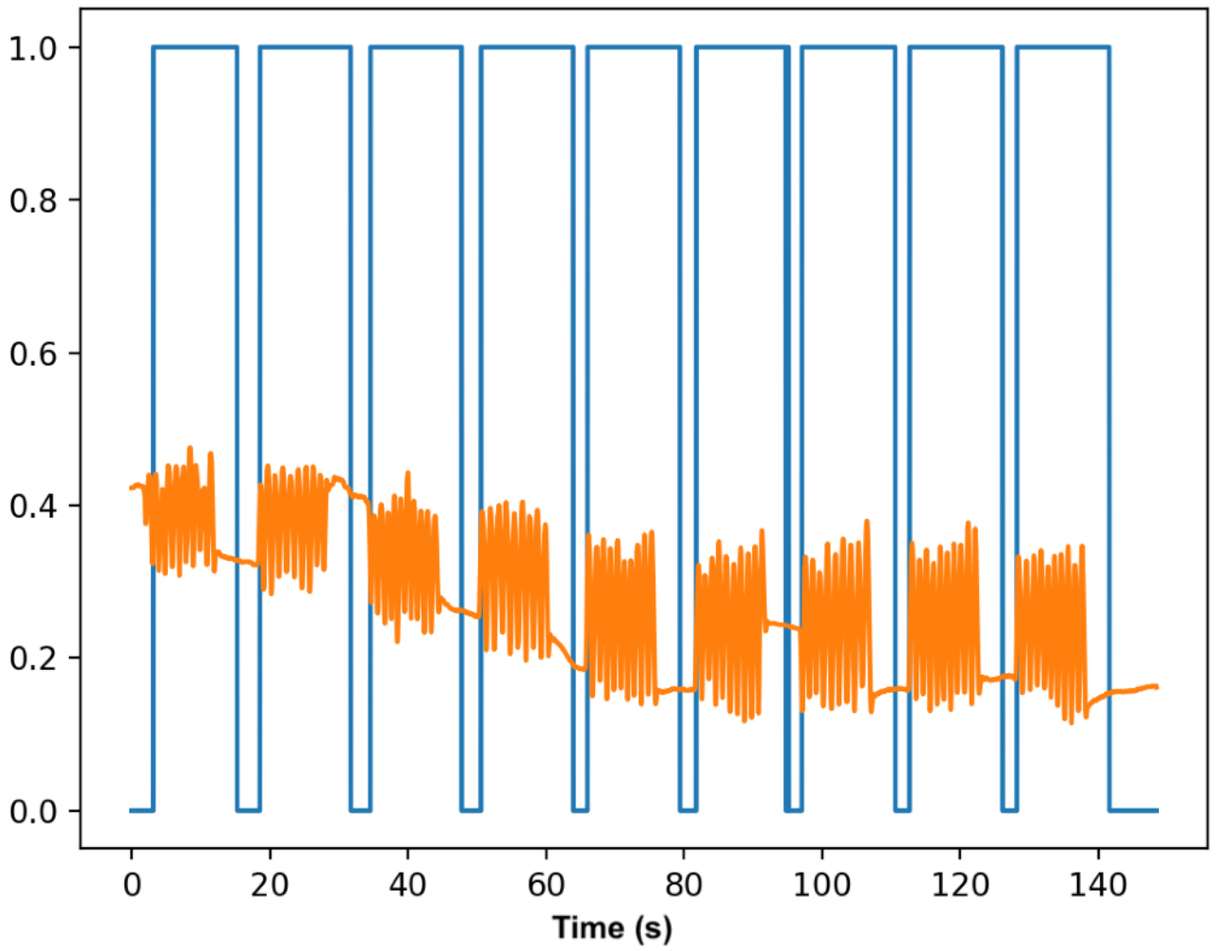
Rhythmic & Discrete Pose Imitation

- 2D Pose Estimation + 3D Transformation
- No Contact
- So when do we switch?



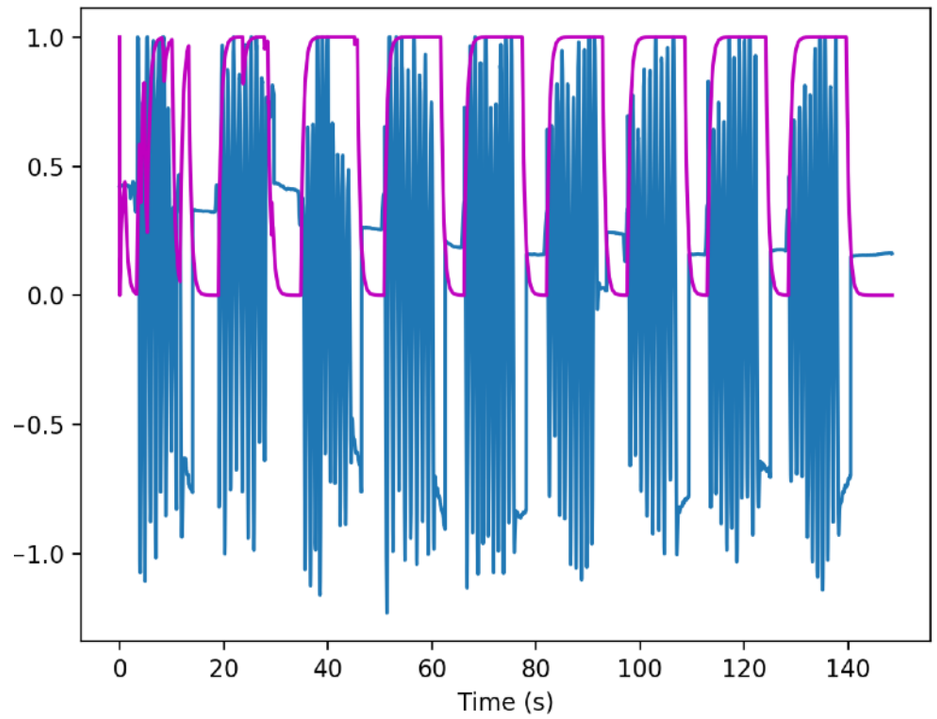
Classification

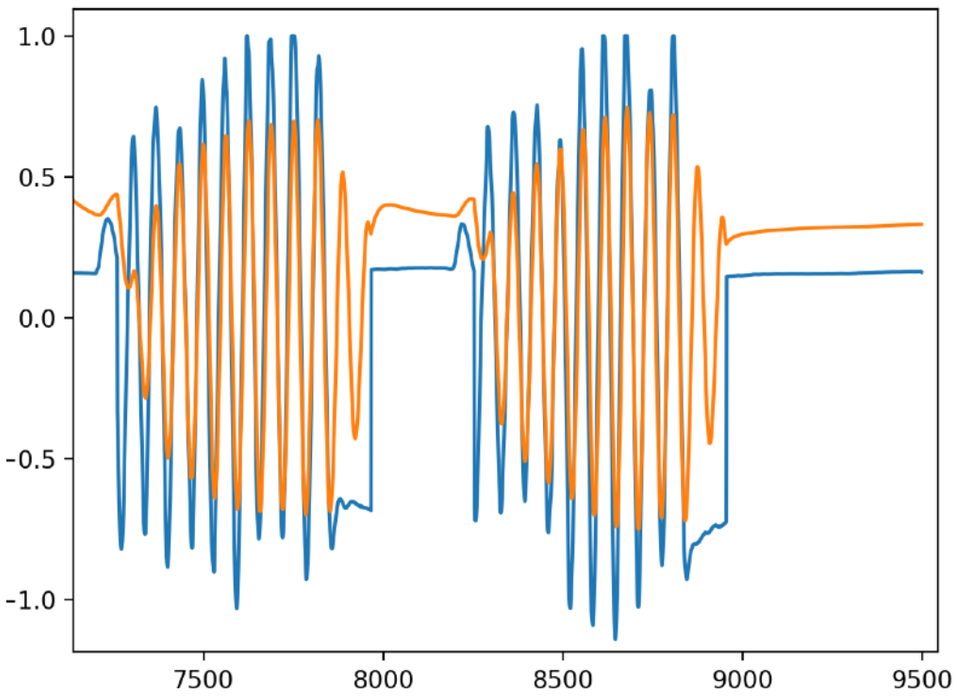
- $C(x,t) = \sum_{N=1}^{n} P(\{x_{t-N} \dots x_t\}) + \alpha \cdot S(\{x_{t-N} \dots x_t\})$
- $P(x) = max(FFT(x)) - \overline{FFT(x)} - stdDev(FFT(x))$
- Evaluated on 4457.53 s of acquired human data
- Precision:65%
- Recall: 100%
- F1-Score: 0.79



Classification: CPG Integration

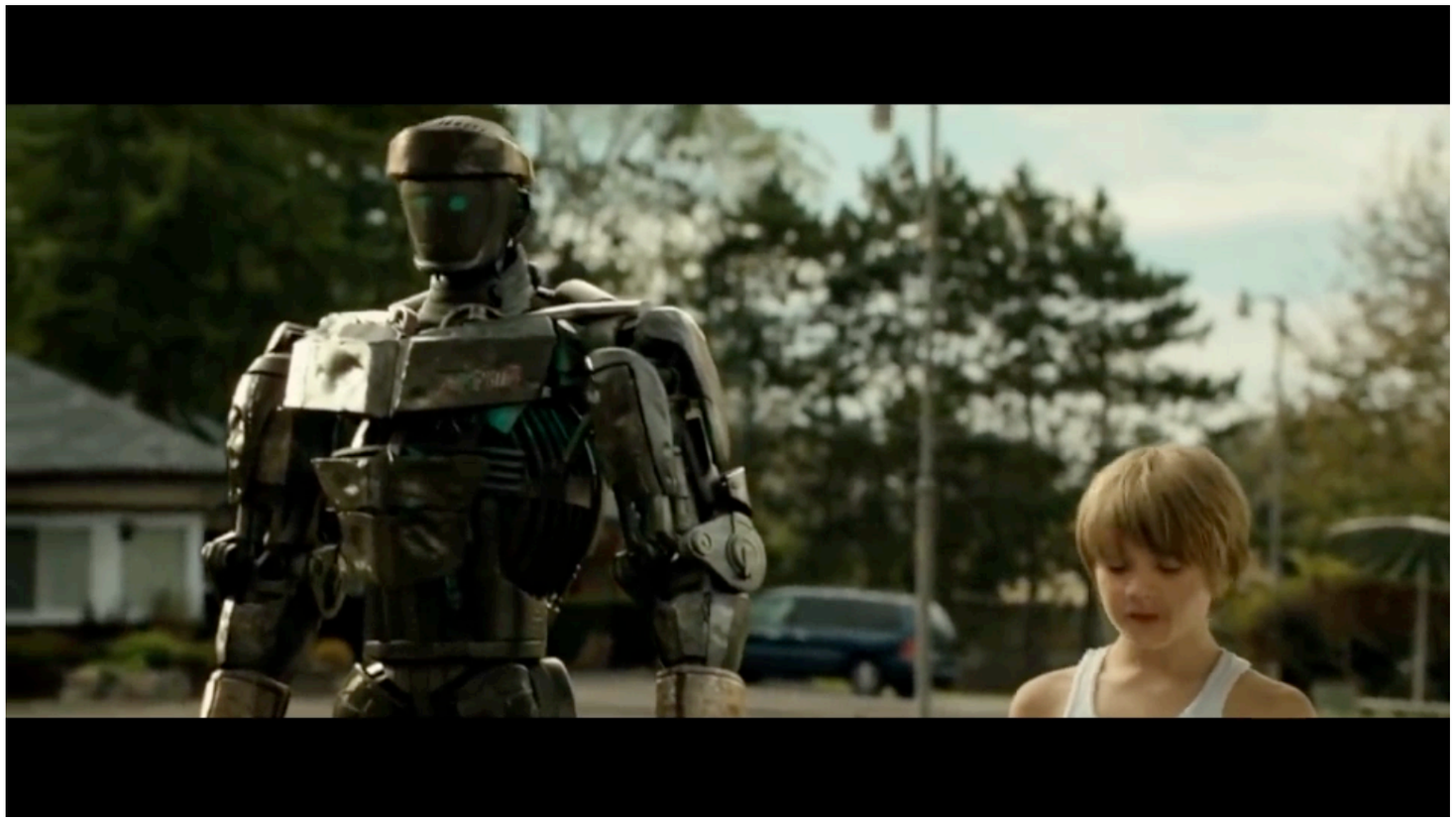
- New Plasticity Rule for σ_F
- $\dot{\sigma}_f = \gamma \cdot \left(\frac{\tanh(100.0 \cdot C(x,t)) + 1.0}{2.0} - \sigma_f \right)$
- Precision: 64%
- Recall: 100%
- F1-Score: 0.78





Perspectives

- Use this in real time interactions
- much more variability



Real Steel (2011)

Thanks for your attention!

Questions?