## Neural Control for Locomotion of Walking Machines

From Biological Inspiration to Implementation on the Machines

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### Presentation outline

- **Biological locomotion control**
- **Sensor-driven neural control (CPG) of a six-legged walking machine**
  - **Omnidirectional walking**
  - **Versatile reactive behaviors**
- **Adaptive reflex neural control (reflex-based mechanism) of a biped robot**
  - **Fast dynamic walking**
  - **Adaptive walking**
- **Conclusions**

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### Animal locomotion

Climbing

Running

Flying

Walking

Crawling

Swimming

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### Biological locomotion control

**Biomechanics:**

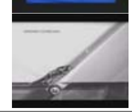


**Neural control:**

- Central Pattern Generator (CPG)[1]

- Reflexes (local motor response to a local sensation)[2]

- Higher control centers (brain for e.g., posture[3], direction)



Brain-lesioned Cockroach
Incline 45 degrees

[1] Orlovsky, G. N.; Deliagina, T. G.; Grillner, S. (1999). Neural Control of Locomotion. From Mollusc to Man. New York: Oxford University Press
[2] Cruse, H. (1990) What mechanisms coordinate leg movement in walking arthropods? Trends in Neurosciences 13, 15-21.
[3] Abbott A. (2007) Biological robotics: working out the bugs, Nature. 2007 Jan 18;445(7125):250-3

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**Sensor–driven neural control of the six-legged walking machine *AMOS***

### Modular design

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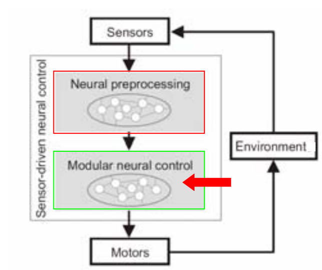
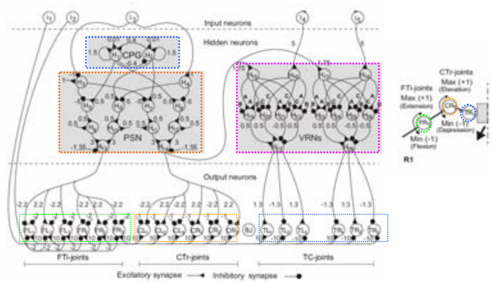
### Sensor–driven neural control

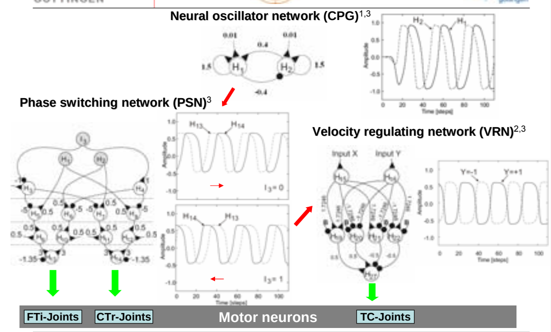


**Modular neural network**




The thoraco-coxal (TC-) joint enables forward (+) and backward (−) movements
The coxa-trochanteral (CTr-) joint enables elevation (+) and depression (−) of the leg
The femurtibia (FTi-) joint enables extension (+) and flexion (−) of the tibia

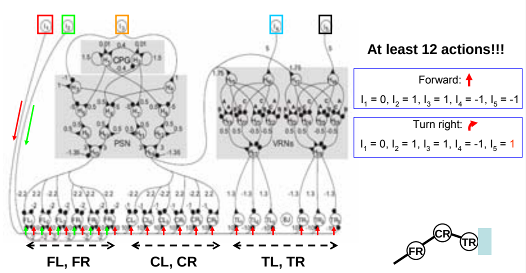





[1] Pasemann, F., Hild, M., Zahedi, K. *SO(2)-Networks as Neural Oscillators*, Proceedings IWANN 2003, LNCS 2686, Springer, Berlin, pp. 144-151, 2003.
[2] Fischer, J. *A modulatory learning rule for neural learning and metalearning in real world robots with many degrees of freedom*. Ph.D. thesis, University of Muenster, Germany, 2004.
[3] Manoonpong, P.; Pasemann, F.; Woergoetter, F. Sensor-Driven Neural Control for Omnidirectional Locomotion and Versatile Reactive Behaviors of Walking Machines. *Robotics and Autonomous Systems*, doi:10.1016/j.robot.2007.07.004, *Elsevier Science, in press*, 2007.



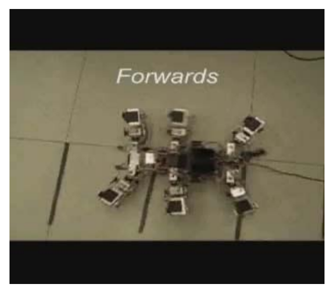
**Neural parameters for generating different walking patterns**




Manoonpong, P.; Pasemann, F.; Woergoetter, F. Sensor-Driven Neural Control for Omnidirectional Locomotion and Versatile Reactive Behaviors of Walking Machines. *Robotics and Autonomous Systems*, doi:10.1016/j.robot.2007.07.004, *Elsevier Science, in press*, 2007.

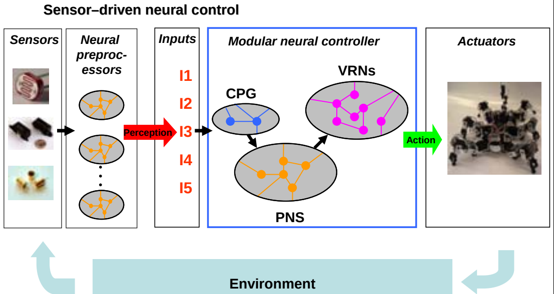


**Omnidiractional walking**






**Sensor–driven neural control**





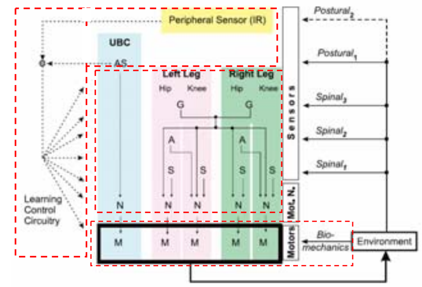

Versatile reactive behaviors : Reflex, escape, obstacle avoidance and phototropism behaviors

Adaptive reflex neural control of the biped robot *RunBot*

## Nested-loop design



## Adaptive reflex neural control[1]



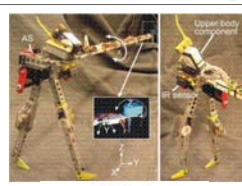

[1] Manoonpong, P.; Geng, T.; Kulvicius, T.; Porr, B.; Wörgötter, F. (2007) Adaptive, Fast Walking in a Biped Robot under Neuronal Control and Learning. *Public Library of Science Computational Biology* (PLoS Comput Biol), 3(7), e134, doi:10.1371/journal.pcbi.0030134

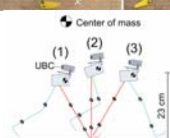


## Biomechanics (RunBot)[1]

**Special features :**

- Small, curved feet allowing for rolling action;
- Unactuated, hence light, ankles;
- Lightweight structure;
- Light and fast motors;
- Proper mass distribution of the limbs;
- Properly positioned mass center of the trunk.

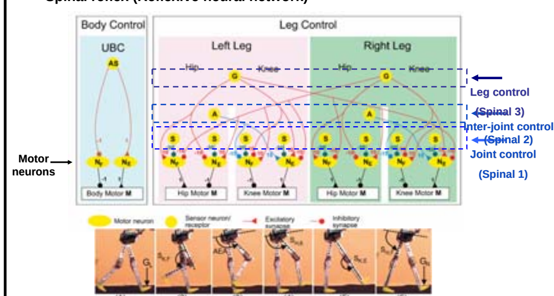



The RunBot system has been originally developed by Dr. Tao Geng

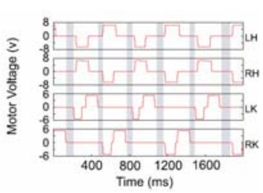


## Spinal reflex (Reflexive neural network)





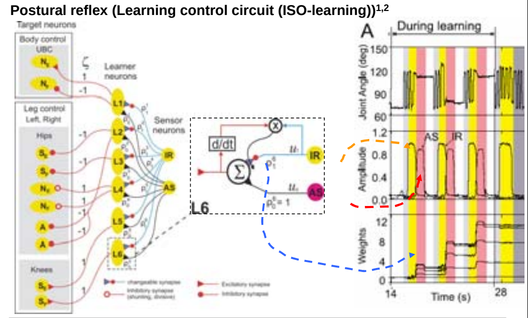

*Passive walking properties (Biomechanical design)*




Changing speed on the fly



## Postural reflex (Learning control circuit (ISO-learning))[1,2]




[1] Manoonpong, P.; Geng, T.; Kulvicius, T.; Porr, B.; Wörgötter, F. (2007) Adaptive, Fast Walking in a Biped Robot under Neuronal Control and Learning. *Public Library of Science Computational Biology* (PLoS Comput Biol), 3(7), e134, doi:10.1371/journal.pcbi.0030134
[2] Porr B, Wörgötter F (2003) Isotropic sequence order learning in a closed loop behavioural system. Roy Soc Phil Trans Mathematical Physical Engineer Sci 361: 2225–2244.

*Adaptive walking on different terrains (learning mechanism)*

Learning to walk
up a ramp

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**Conclusions**

• **Sensor-driven neural control = Neural perprocessing unit + Modular neural control unit (modular design)**
-Neural oscillator network (CPG)
-Velocity regulating networks (spot turning, backward walking)
-Phase switching network (lateral movements)

• **Adaptive reflex neural control (nested-loop design)**
- Biomechanical level (passive walking properties)
- Spinal reflex level (fast walking)
- Postural reflex level (adaptive walking)

• **Proposed neural control designs can be powerful techniques to better understand and solve sensorimotor coordination problems of many degrees-of-freedom systems.**