Developmental relation between infant locomotion and cognition

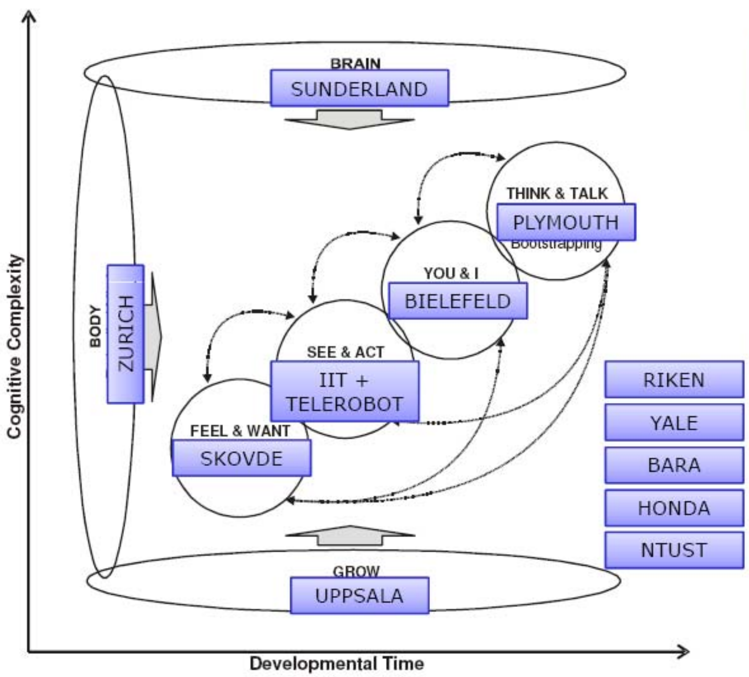
Gauss Lee

University of Skövde

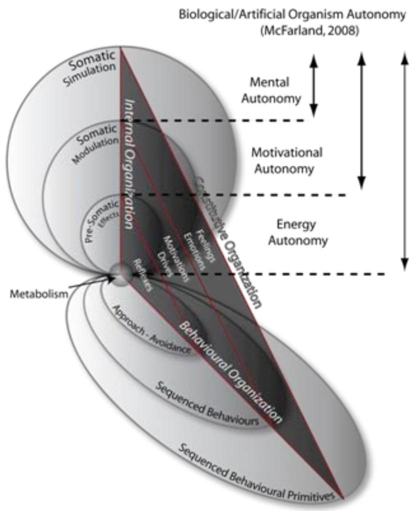
Supervisors: Tom Ziemke and Robert Lowe

RobotDOC Project and Task

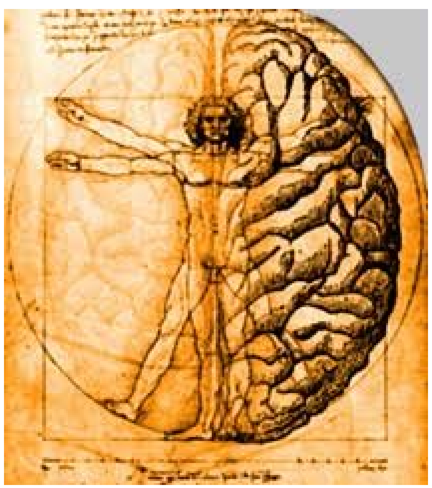
Themes and Training Nodes



Task: Affective modulation of embodied cognition



Adapted from Ziemke & Lowe 2010



- **Affective modulation(high-level):** perception, memory, attention, cognition , etc.

- **Embodied cognition:** the ability to move, activities and interactions with our environment and the naive understanding of the world that is built into the body

Consistent with diagram on the left

Motor ability(locomotion) → Cognition ability(affective modulation)

Clearfield's experimental research on links between development of locomotion(crawling->walking) and cognition(spatial memory…) (2004,2008,2010)

?

Background on Infant Development

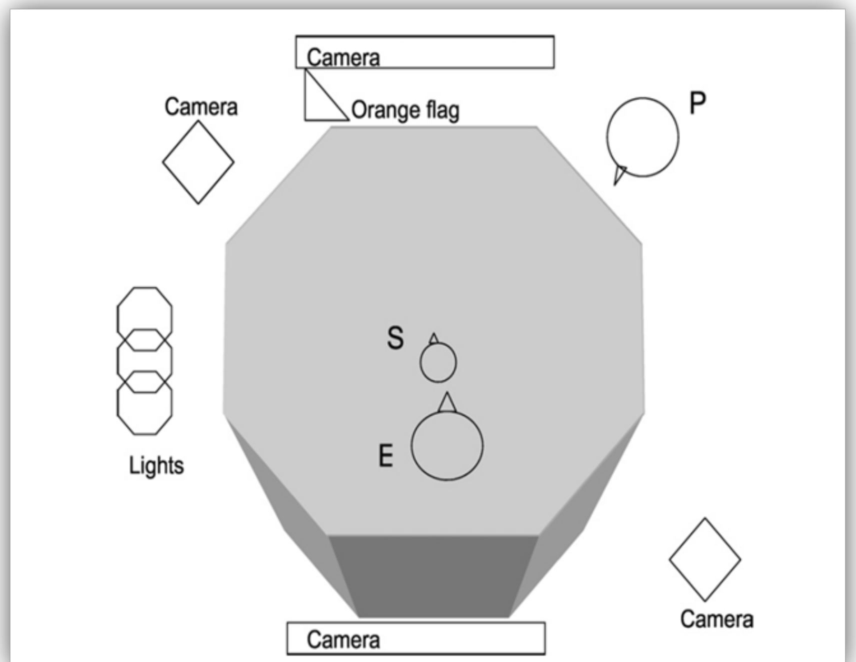
- **The onset of crawling marks a motor, cognitive and social milestone** (e.g., Bertenthal, Campos, & Kermoian, 1994; Campos, Bertenthal, & Kermoian, 1992; Rader, Bausano, & Richards, 1980; Richards & Rader, 1981).

- Independent locomotion “a **control parameter**, and **a mobilizer** that changes the intra-psychic states of the infant, the social and nonsocial world around the infant, and the interaction of the infant with that world(Campos et al, 2000)

- Transition from crawling to independent walking suggests that there may be **emotional changes at the onset of walking**, with walking infants demonstrating more joy, elation, and willfulness (e.g., Biringen, Emde, Campos, & Appelbaum, 1995; Greenacre, 1971; Mahler, Pine, & Bergman, 1975).

- **Crawling and walking infants also engaged in different exploratory behaviors** when faced with steep and shallow slopes that they needed to descend (e.g., Eppler, Adolph, Marin, Weise, & Clearfield, 2000; Adolph, 1997; Adolph, Eppler, & Gibson, 1993)

Experiment 1(Clearfield,2004)



- Result1: infants with more locomotion experience might be more likely to cover more ground searching.
- Result2:the behaviors required comes from the soft assembly of perceptual inputs, memory for location and motor skills and the onset of walking disrupts infants' use of landmarks, at least initially.

1.locomotion or its experience can improve spatial memory(effect ranking: active>passive)

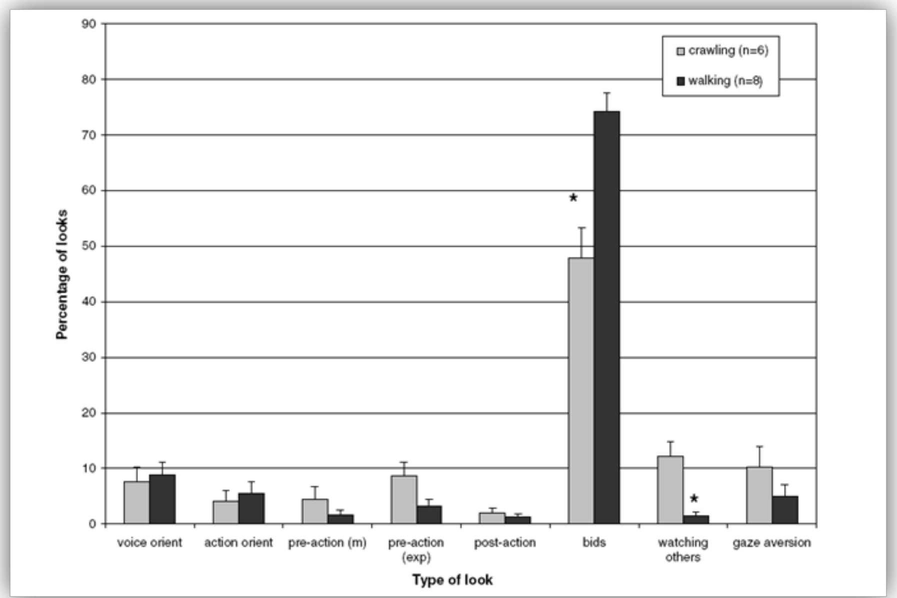
2.Locomotor experience is an important part of spatial learning in assembling the inputs of perceptual inputs, memory and motor skills.

3.The knowledge gained across months of crawling experience did not transfer to walking infants.

Aims at finding out the links between transition from crawling to walking and spatial memory(place learning and cue learning)

What the infants remember about how a space is mapped out is inextricably linked to their movements through the space.(Clearfield, 2004)

Experiment 2(Clearfield, 2008)



Aim to verify that development from crawlers to walkers marks the development from passive social looks(engagement) to active.

- Result: the change from watching others communicate to initiating social interactions suggests that infants are maturing from passive to active participants in their social environment and this effect can best be explained by transition to independent walking.
- Conclusions :
- 1.infants are more interested in actively exploring their environments than in using others' appraisals as a catalyst.
- 2.major changes in locomotor development may be connected to major changes in social development. (onset of crawling and walking->changes in cognitive and perceptual development.)

Experiment 3(Clearfield, 2010)

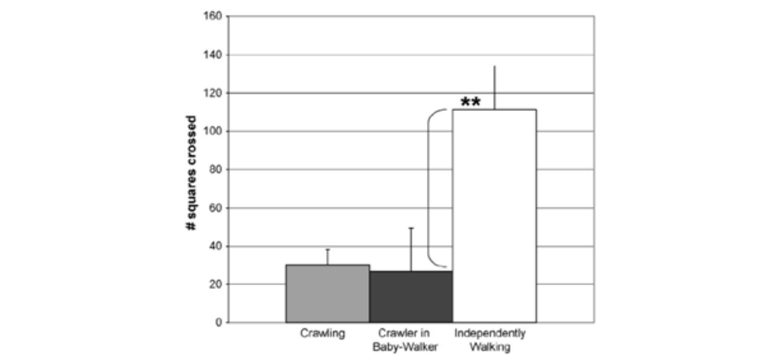


Fig. 1. Number of squares crossed by locomotor status. The data for the infants while crawling and in a baby-walker are described in Experiment 1, and the comparison between crawling infants in the baby-walker and age-matched walking infants are described in Experiment 2. $^{**}p < .01$.

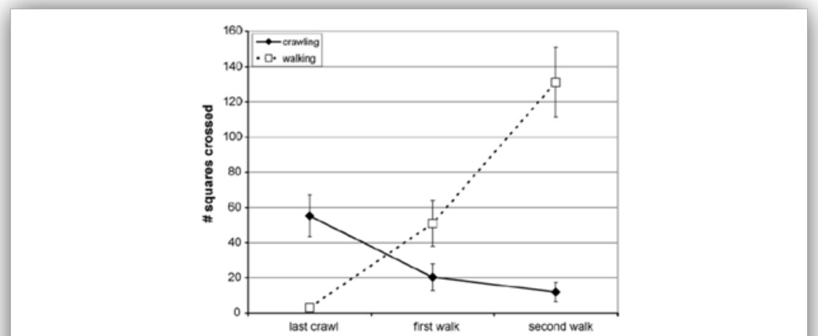


Fig. Number of squares crossed, both crawling and walking, by session. Infants crawled significantly more in their last crawl session compared to their first walk session and infants walked significantly more in successive sessions.

To prove onset of independent walking is also a milestone in the development of infants' social interaction

- Result1:changing postures from crawling to upright locomotion did not affect the manner in which the infants moved through the space, looked around or interacted with adults
- Result2:learning to walk independently creates a system-wide shift in interaction style, which cannot be explained by age or maturation(age-matched infants are involved).
- Result3:by replicating the results longitudinally, it shows the transition to independent walking itself changed how infants interact with others.
- Conclusions:
- Independent walking served as a control parameter, resulting in a reorganization of infant experiences , where walking operates through a complex formula of intervening maturation-experience variables in a causal nexus.

Motor ability(locomotion) → Cognition ability(affective modulation)

Clearfield's experimental research on links between development of locomotion(crawling->walking) and cognition(spatial memory…) (2004,2008,2010)

The key idea regarding the interaction between the person and the environment is one that is shared with Dynamic System Theory(DST). According to it, development is best described as the emergent product of many decentralized and local interactions that occur in real time.

These many interactions are ever-changing, and should be conceptualized as a constantly changing set of relationships among inextricably linked parts. New forms then arise from ongoing processes that are intrinsic to the system. Thus, systems can generate novelty (new behaviors like new forms of locomotion or interaction) through their own activity. Thus, we can think about development as a series of patterns of behavior that become more and less stable over time. During periods of stability, we would expect useful and efficient behaviors to be repeated. But it is during periods of instability when new forms, new behaviors, should be more likely to arise.(Clearfield,2010)

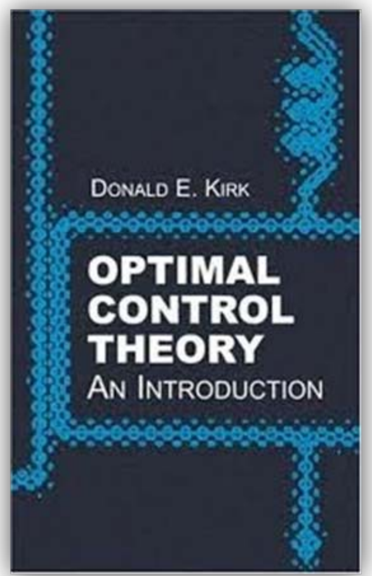
Conclusions

- we can think of the developing infant as a complex system made up of many individual elements embedded in a rich context. During periods of stability, all the elements of the system work together smoothly. During periods of instability, the system is open to multiple flexible solutions and the emergence of new forms.
- The transition to independent walking appears to be one of those periods of instability. It becomes the core of system-wide changes across many developing domains.(Clearfield, 2010)

Locomotion models

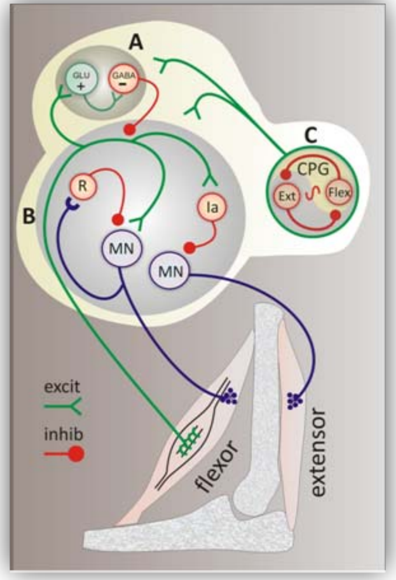
- Modern control theory

  Optimal control theory



- CPG(Central pattern generator)

  Emphasis on finding a neurodynamic model which can explain clearfield's phenomena



Introduction to CPG

- "**Central pattern generators (CPGs)** can be defined as neural networks that can endogenously (i.e., without rhythmic sensory or central input) produce rhythmic patterned outputs“ or as "neural circuits that generate periodic motor commands for rhythmic movements such as locomotion.(Hooper, Scott L,1999)
- Spinal cord
- Locomotion in vertebrates:
- decerebrated cat(Shik,1991), lamprey and salamander (fictive locomotion)
- Different levels of abstraction
- Hodgkin-Huxley neuron model(representation of ion channels), nonlinear oscillator(Matsuka, Hopf, etc.)

A systematic approach to model CPG network(Righetti, 2008)

- 1. Desirable properties of CPG based controller (oscillators)
- Requirement :1. As simple as possible 2.capable of integrating sensory feedback
- 2. Architecture of coupled CPG network
- Requirement: 1.structurally stable 2.generic and scalable architecture 3.allow more complex behaviors 4.generate several gaits and smooth gaits transition
- 3. Sensory feedback
- Requirement: 1. stable to parameter uncertainty and unknown environment 2.more generic feedback (vestibular info)

Gaits transition in CPG network

Golubitsky and Stewart, 2

Righetti,2008

Possible solutions in the trot network		
H	K	Pattern of oscillations
$\mathbb{D}_4$	$\mathbb{D}_4$	$x(t), x(t), x(t), x(t)$
	$\mathbb{Z}_2(\tau)\times\mathbb{Z}_2(\sigma)$	$x(t), x(t+\frac{1}{2}), x(t+\frac{1}{2}), x(t)$
$\mathbb{Z}_4(\varrho)$	I	$x(t), x(t\pm\frac{1}{4}), x(t\pm\frac{3}{4}), x(t+\frac{1}{2})$
$\mathbb{Z}_2(\tau)\times\mathbb{Z}_2(\sigma)$	$\mathbb{Z}_2(\tau)\times\mathbb{Z}_2(\sigma)$	$x(t), y(t), y(t), x(t)$
	I	$x(t), y(t), y(t+\frac{1}{2}), x(t+\frac{1}{2})$
$\mathbb{Z}_2(\kappa)$	$\mathbb{Z}_2(\kappa)$	$x(t), x(t), y(t), y(t)$
	I	$x(t), x(t+\frac{1}{2}), y(t), y(t+\frac{1}{2})$
$\mathbb{Z}_2(\nu)$	$\mathbb{Z}_2(\nu)$	$x(t), y(t), x(t), y(t)$
	I	$x(t), y(t), x(t+\frac{1}{2}), y(t+\frac{1}{2})$
$\mathbb{Z}_2(\sigma)$	$\mathbb{Z}_2(\sigma)$	$x(t), y(t), y(t), z(t)$
	I	$x(t), y(t), y(t+\frac{1}{2}), z(t)$
$\mathbb{Z}_2(\tau)$	$\mathbb{Z}_2(\tau)$	$x(t), y(t), z(t), x(t)$
	I	$x(t), y(t), z(t), x(t+\frac{1}{2})$
I	I	$x(t), y(t), z(t), w(t)$

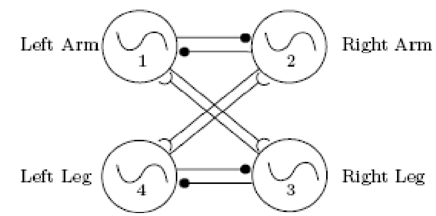


Figure : The architecture of the CPG

K	Possible Periodic Solutions	Stability
Γ	$x_1(t)=x_2(t)=x_3(t)=x_4(t)$	Unstable
$\{I,(12)(34)\}$	$x_1(t)=x_2(t)=x_3(t+\frac{T}{2})=x_4(t+\frac{T}{2})$	Unstable
$\{I,(13)(24)\}$	$x_1(t)=x_2(t+\frac{T}{2})=x_3(t)=x_4(t+\frac{T}{2})$	Asym. stable
$\{I,(14)(23)\}$	$x_1(t)=x_2(t+\frac{T}{2})=x_3(t+\frac{T}{2})=x_4(t)$	Unstable

Figure From the symmetry of the network, we derived the possible pattern of synchronization according to the possible subgroups of spatial symmetry. For each subgroup, we indicate the possible periodic solutions and their stability. The stability of the solutions was evaluated numerically, as shown in Figure 4.6.

Theorem 1 H/K Theorem[51] *Let Γ be the symmetry group of a coupled cell network in which all cells are coupled and the internal dynamics of each cell is at least two-dimensional. Let $K \subset H \subset \Gamma$ be a pair of subgroups. Then there exist periodic solutions to some coupled cell systems with spatio-temporal symmetries H and spatial symmetries K if and only if H/K is cyclic and K is an isotropy subgroup. Moreover, the system can be chosen so that the periodic solution is asymptotically stable.*

Cognition(Affective) models

- Somatic (body-based) theories of emotion
  - Somatic marker hypothesis, Homeostatic regulation(Damasio)
- Neural (brain-based) theories of emotion
  - LeDoux's dual route model (1996, 2005)
- Appraisal theory approach
  - Structural vs Process-oriented models
- Dynamic systems approach
  - Component process model

Dynamic Field Theory(DFT)
The link between dynamic system theory and motor behavior:
1.Actions reflect a dynamic balance among stability, instability, flexibility
2.Behavior is softly assembled from multiple component processes
3.Nonlinear processes!

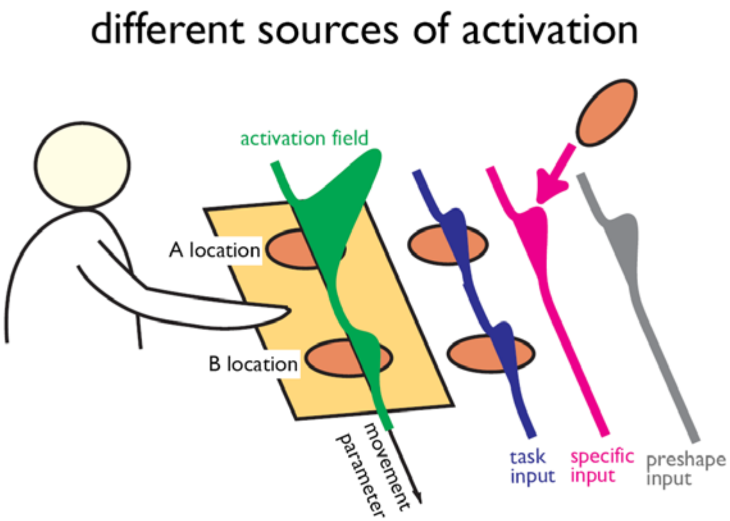
Sensorimotor systems evolve continuously in real time but cognition can jump from one to another.

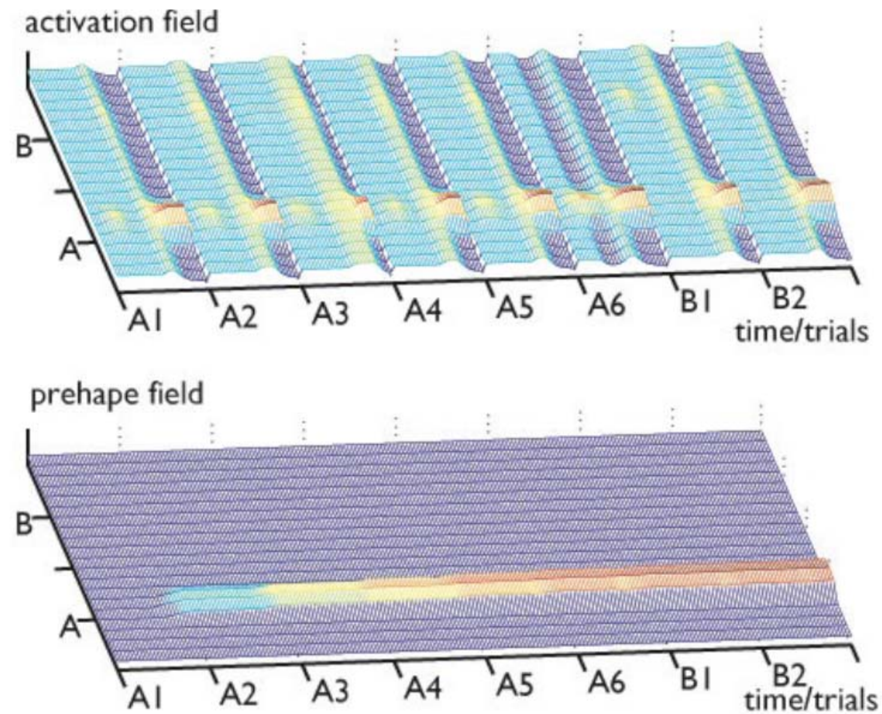
An abstract representation which is linkable in context to real-time sensorimotor activity
(Spencer,2003,2006,2008)

A not B problem

Amari equation

$$\tau \dot{u}(x,t) = -u(x,t) + h + S(x,t) + \int w(x-x')\sigma(u(x',t))\,dx'$$



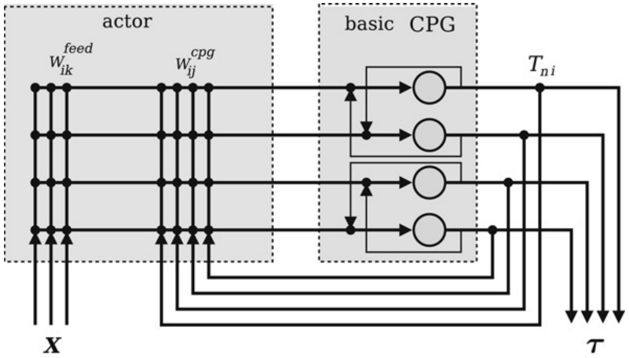


Summary and future work

Cognition(affective …)

DFT(Representation of context and sensorimotor)

Clearfield assumption based on DST



Locomotion

CPG network(transition from crawling to walking)

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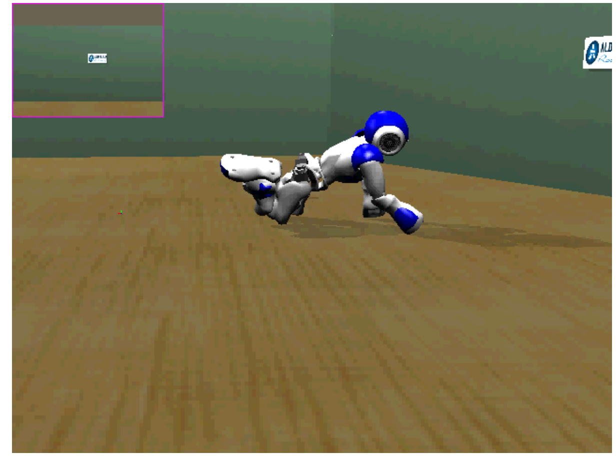
- Control of Legged Locomotion using Dynamical Systems:Design Methods and Adaptive Frequency Oscillators, Ludovic Righetti, PhD thesis of RobotCub
- A modular bio-inspired architecture for movement generation for the infant-like robot *iCub,* Sarah Degallier, Ludovic Righetti, Lorenzo Natale, IST-2004-004370: RobotCub and by the Swiss National Science Foundation
- Reinforcement learning for a biped robot based on a CPG-actor-critic method, Yutaka Nakamuraa, Takeshi Moria, Masa-aki Satoc, Neural Networks 20 (2007) 723–735

Thank you so much!

Tack så mycket!

Videos about crawling iCub and NAO

Crawling iCub



Crawling NAO under control of CPG

Change parameter, change crawling direction

Questions about gait transition

Possible solutions in the walk network		
H	K	Pattern of oscillations
$\mathbb{Z}_4$	I	$x(t), x(t+\frac{1}{2}), x(t\pm\frac{1}{4}), x(t\pm\frac{3}{4})$
	$\mathbb{Z}_2$	$x(t), x(t), x(t+\frac{1}{2}), x(t+\frac{1}{2})$
	$\mathbb{Z}_4$	$x(t), x(t), x(t), x(t)$
$\mathbb{Z}_2$	I	$x(t), x(t+\frac{1}{2}), y(t), y(t+\frac{1}{2})$
	$\mathbb{Z}_2$	$x(t), x(t), y(t), y(t)$
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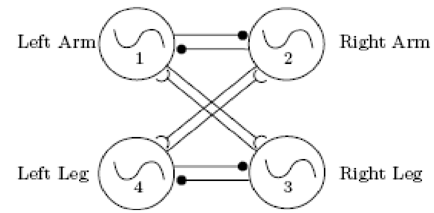
$\mathbb{Z}_2(\tau)\times\mathbb{Z}_2(\sigma)$	$\mathbb{Z}_2(\tau)\times\mathbb{Z}_2(\sigma)$	$x(t), y(t), y(t), x(t)$
	I	$x(t), y(t), y(t+\frac{1}{2}), x(t+\frac{1}{2})$
$\mathbb{Z}_2(\kappa)$	$\mathbb{Z}_2(\kappa)$	$x(t), x(t), y(t), y(t)$
	I	$x(t), x(t+\frac{1}{2}), y(t), y(t+\frac{1}{2})$
$\mathbb{Z}_2(\nu)$	$\mathbb{Z}_2(\nu)$	$x(t), y(t), x(t), y(t)$
	I	$x(t), y(t), x(t+\frac{1}{2}), y(t+\frac{1}{2})$
$\mathbb{Z}_2(\sigma)$	$\mathbb{Z}_2(\sigma)$	$x(t), y(t), y(t), z(t)$
	I	$x(t), y(t), y(t+\frac{1}{2}), z(t)$
$\mathbb{Z}_2(\tau)$	$\mathbb{Z}_2(\tau)$	$x(t), y(t), z(t), x(t)$
	I	$x(t), y(t), z(t), x(t+\frac{1}{2})$
I	I	$x(t), y(t), z(t), w(t)$

Table 4.1: These two tables show the different possible solutions correspon[illegible] trot and walk networks. For both networks we show the possible pattern of solution for the 4 cells together with the associated group of spatial (K) and spatiotemporal (H) symmetries. For example $(x(t), y(t), y(t+\frac{1}{2}), z(t))$ means that the solutions for cells 2 and 3 are the same up to a time shift of half a period, while the solutions of cells 1 and 4 are different. For the walk network $\mathbb{Z}_4$ is the group generated by ((1423)), while $\mathbb{Z}_2$ is generated by ((12)(34)). For the trot network $\mathbb{D}_4$ is the full group of symmetries of the gait, for the other groups we show the generators in parentheses, where $\tau = ((14)(2)(3))$, $\sigma = ((1)(23)(4))$, $\kappa = ((12)(34))$, $\nu = ((13)(24))$ and $\varrho = ((1243))$.



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$\{I, (14)(23)\}$	$x_1(t) = x_2(t+\frac{T}{2}) = x_3(t+\frac{T}{2}) = x_4(t)$	Unstable

Figure From the symmetry of the network, we derived the possible pattern of synchronization according to the possible subgroups of spatial symmetry. For each subgroup, we indicate the possible periodic solutions and their stability. The stability of the solutions was evaluated numerically, as shown in Figure 4.6.

DFT

Amari equation

$$\tau \dot{u}(x,t) = -u(x,t) + h + S(x,t) + \int w(x-x')\sigma(u(x',t))\, dx'$$

where

- time scale is τ
- resting level is $h < 0$
- input is $S(x,t)$
- interaction kernel is

$$w(x-x') = w_i + w_e \exp\left[-\frac{(x-x')^2}{2\sigma_i^2}\right]$$

- sigmoidal nonlinearity is

$$\sigma(u) = \frac{1}{1+\exp[-\beta(u-u_0)]}$$