Neuromorphic Eng. Workshop, *Telluride, 12 Jul. 2005*

Walking and Running of a Quadruped Robot on Irregular Terrain

- The State of Art in Legged Locomotion Study -

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Aichi Expo. Prototype Robot Exhib.
Jun.9-19, 2005

Tekken4

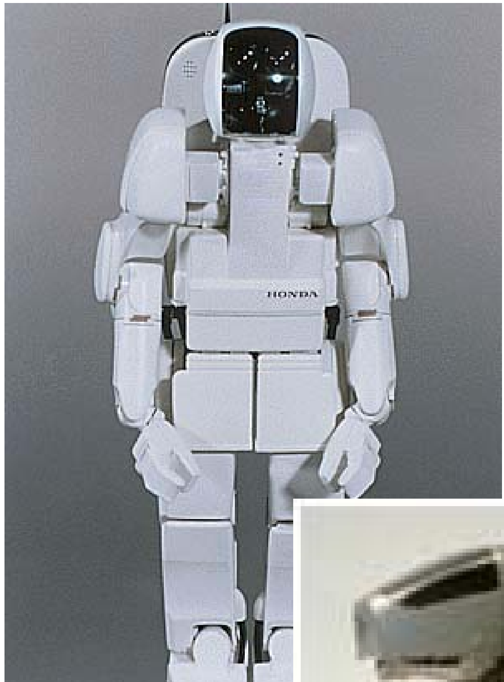
- 32 times Demo
- 3 times TV
- 17,000 people / day

House keeping dog in a garden (rush to the thief and take a picture)

Outlines

- Legged locomotion control methods
- Legged robots based on biological concepts
- Emergingly adaptive walking study
- Adaptive walking of a quadruped robot
- Adaptive running of a quadruped robot
- Summary & Others

Recent Popular Legged Robots in Japan



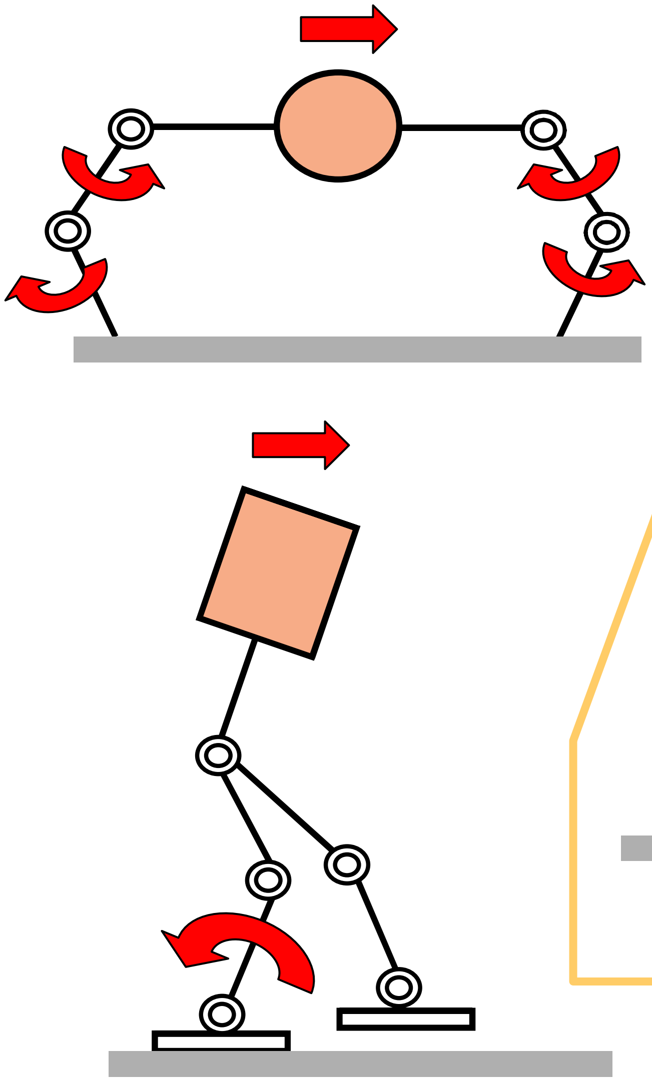
Self-contained!

Adaptive?

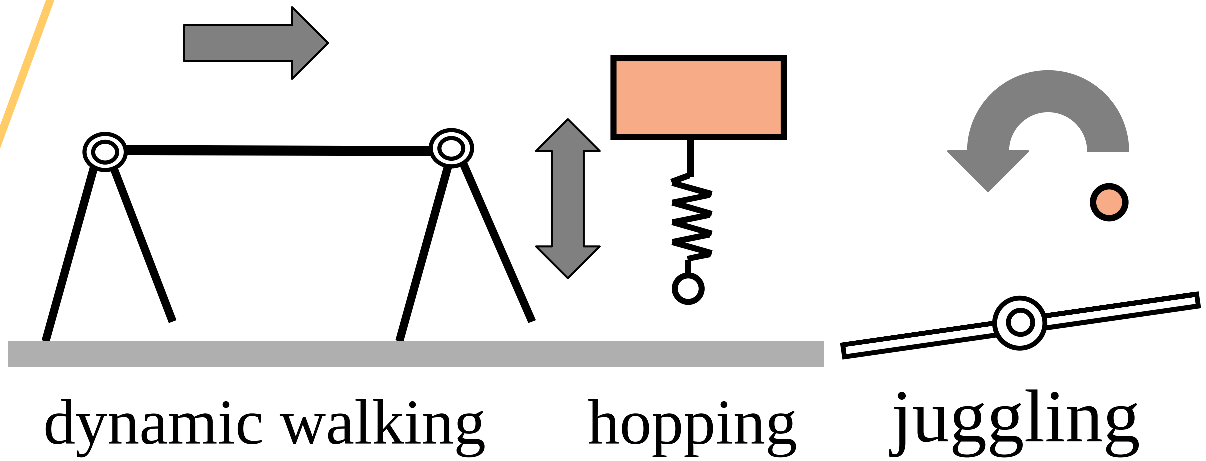
Just following the pre-programmed motion pattern

What is legged locomotion?

Manipulation of a Body

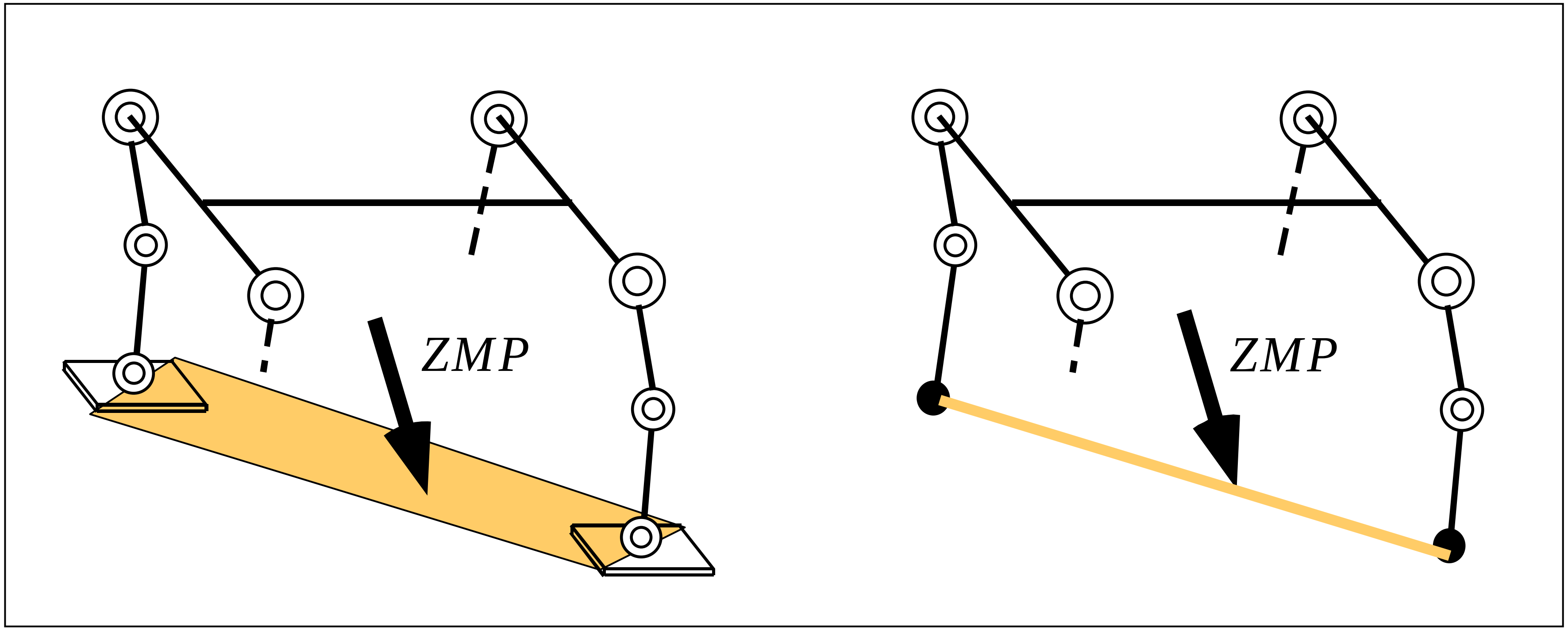


Stabilization of Non-linear Oscillation



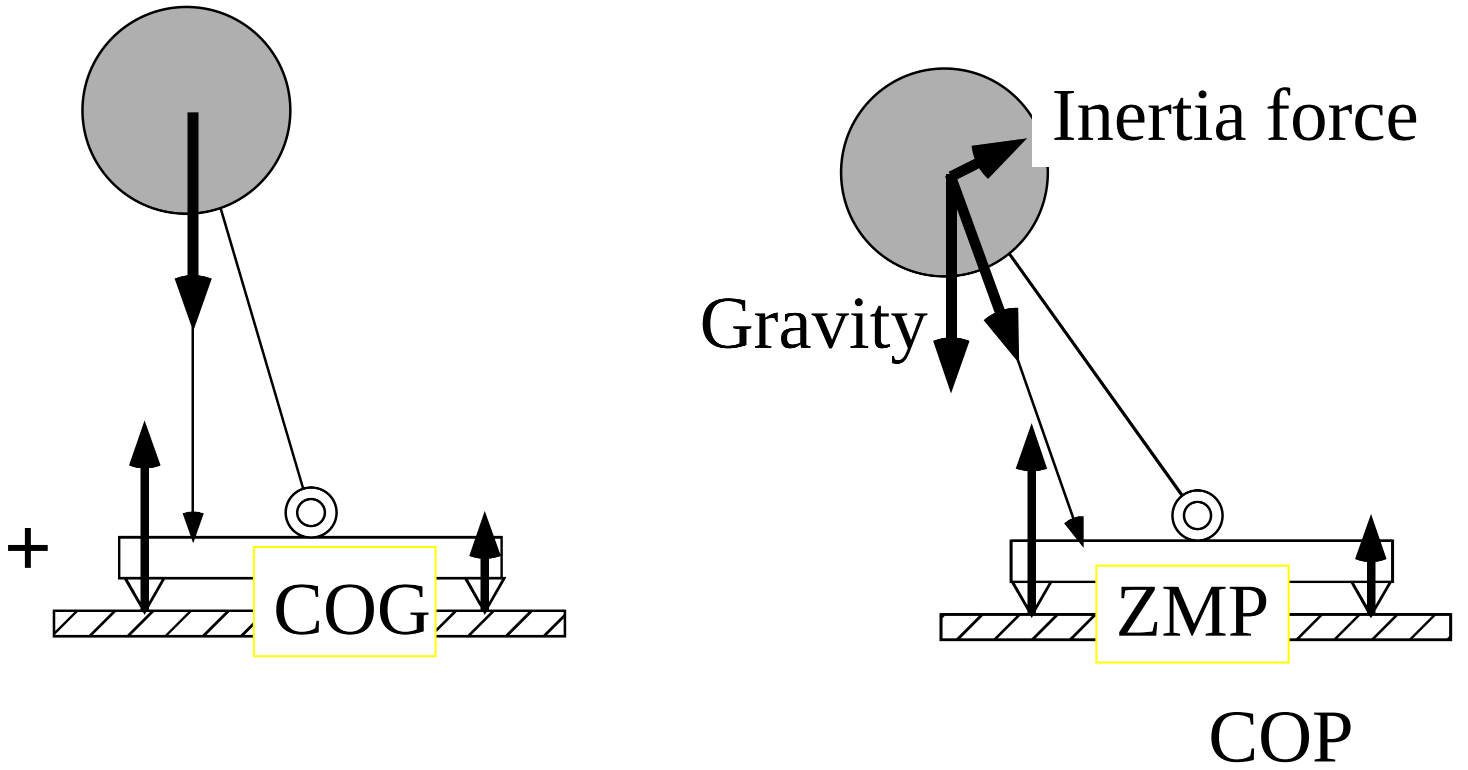
ZMP Based vs. Limit Cycle Based

Zero Moment Point



Stable Limit Cycle on Phase Plane

ZMP Based

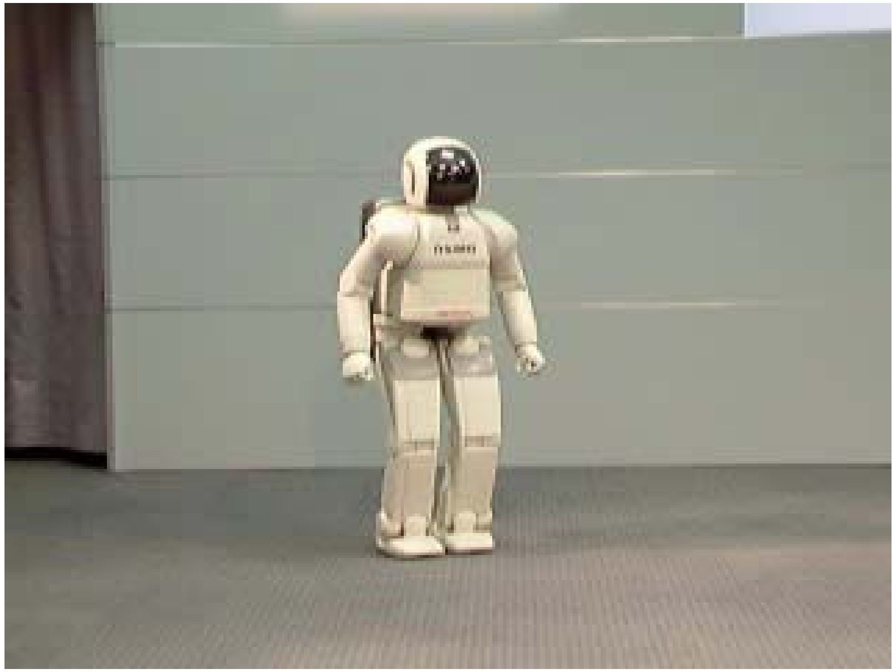


In order to avoid falling down,

realize the given trajectory
as precise as possible.

Control of a arm

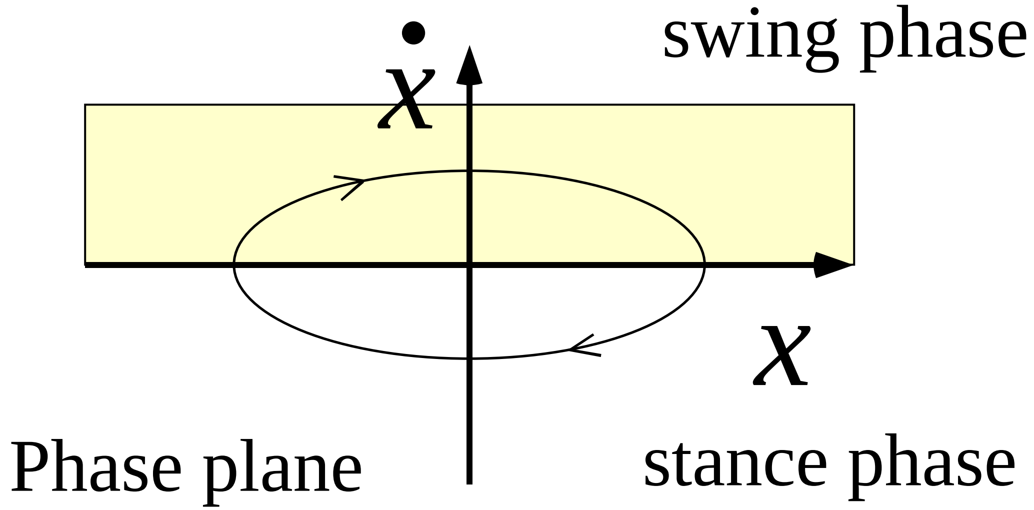
ZMP-based
Motion Generation and Control



Ashimo [Honda, Dec. 2002]

H7 [Tokyo Univ., Jul. 2003]

Limit Cycle Based



To keep the stable oscillation,

Switching stance/swing phases → non-linearity

Limit Cycle based Motion Control

TomCat [Jul. 2003]

the upper bound of
the cyclic period of walking

Passive Dynamic Walking

A walking machine can walk down the slope without actuation.

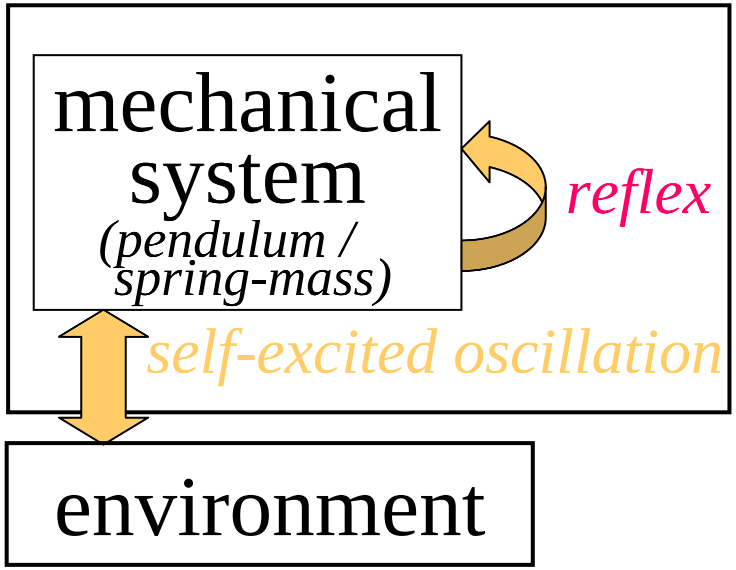
Is the control necessary?

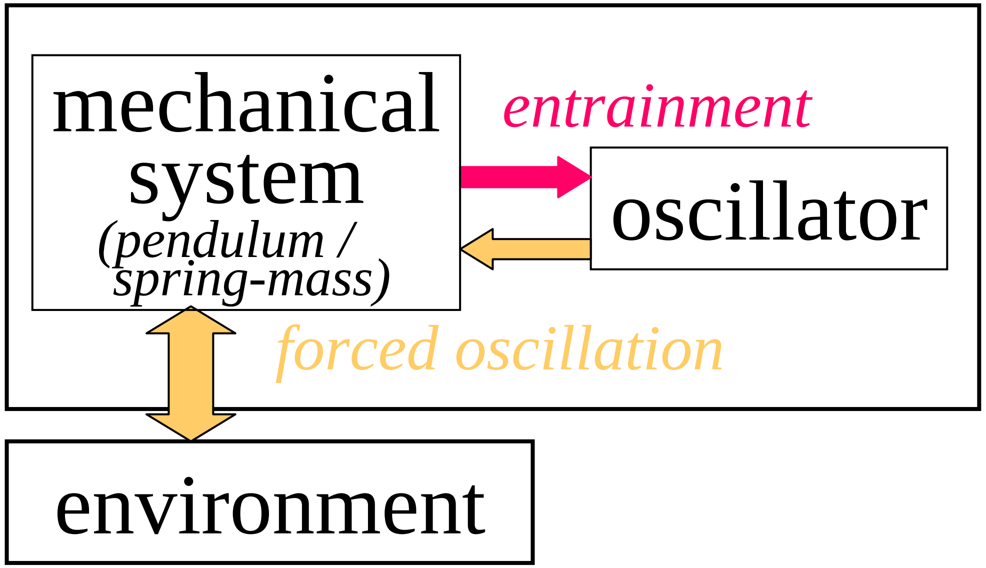
(Cornel Univ：2000)

Adaptive Oscillation
- Self-excited or Enfocred -

[Ono, et al.: 1994]

- self-excited oscillation ex. swinging game
- enforced oscillation + synchronization





Self-excited Walking of Planar Biped

[Ono et al.: IJRR2001, 2004]

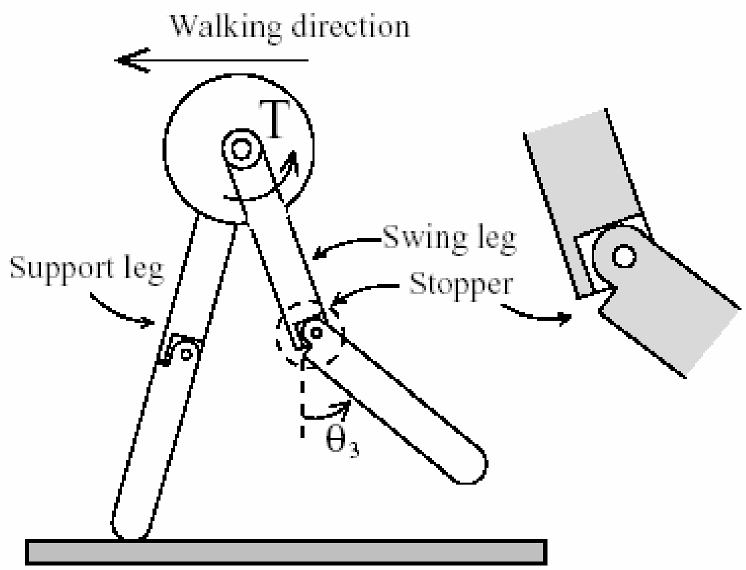


Figure 1: 3-DOF walking mechanism

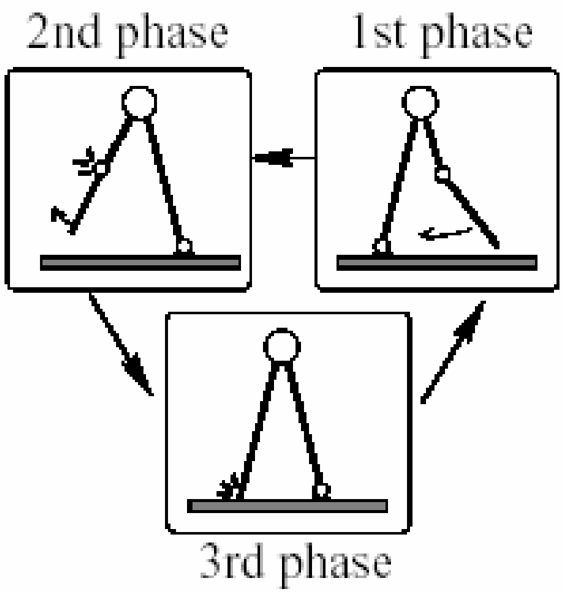


Figure 2: Different phases of biped walking

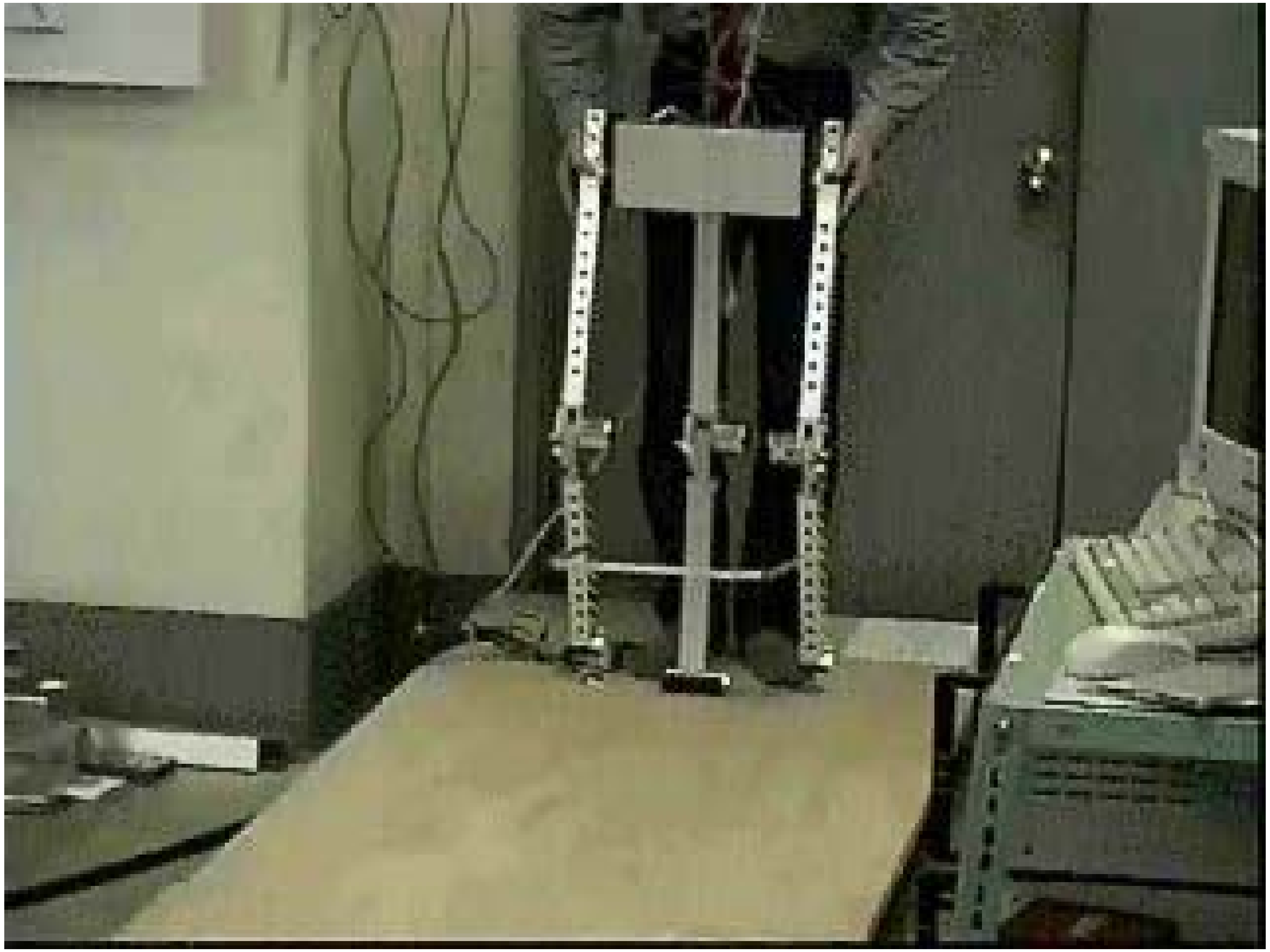
$$T = -k\theta_3$$

Hip joint torque   Knee joint angle

self-excited oscillation
only by sensor feedback

Self-exited Walking
- on flat floor -

[Ono et al.:2000]

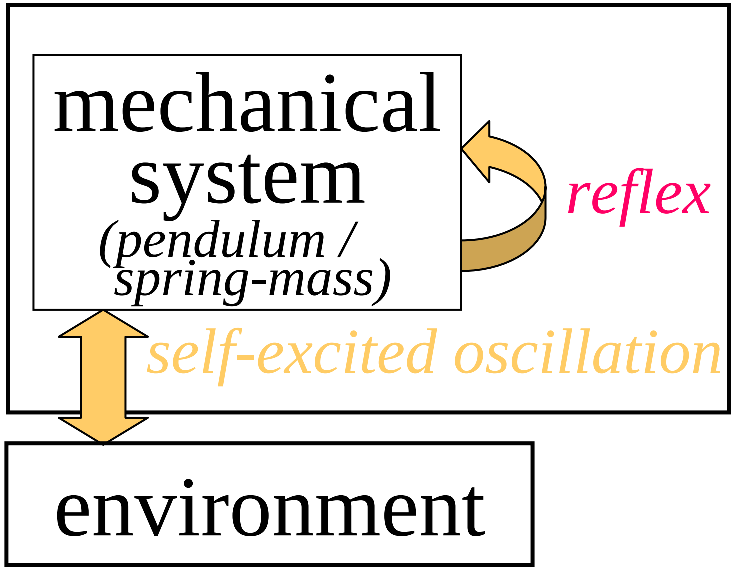


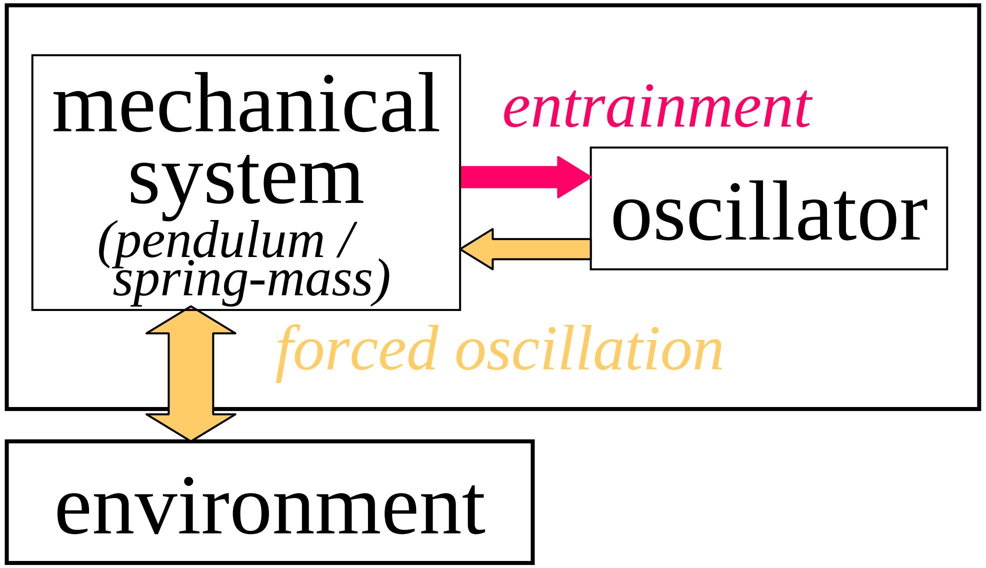
Adaptive Oscillation
- Self-excited or Enfocred -

[Ono, et al.: 1994]

- self-excited oscillation
- enforced oscillation + synchronization

oscillation by CPG (Central Pattern Generator)





Do we need CPG?

for generation of legged locomotion

neural system model
(CPG + reflexes)

passive dynamics
(mechanism)

central ⇔ peripheral

oscillator ⇔ non-oscillator

Grillner,
Cohen,
Ayers,
Ijspeert,
Taga,
Kimura, Tsuchiya,
………

Cruse,
Quinn,
………

•passive dynamic walk
•spring-damper

Blickhan,
Full,
Koditschek,
Buehler,
Cutkosky,
………

CPG Models

Cruse, Ekeberg

- more sensor dependent & more decentralized
- more general
- cyclic period is determined by speed of the body and legs

Taga, Kimura , Lewis, Tsujita&Tsuchiya , Ilg, …

- non-linear oscillator
- time constant or standard cyclic period
- dynamics of mechanism is encoded into parameters of the neural system

argument (BC:2002)

essential for dynamic walking

by Kimura (IJRR2003)

Which Sensor Information is used for Mutual Entrainment of CPG?

- Contact to the ground & AEP-PEP
  - anterior extreme position
  - posterior extreme position
  - Pearson (cat)
  - Cruse (stick insect)
  - Tsuchiya, Tsujita & Aoi (quadruped and biped)
- Joint angle
  - Grillner (lamprey)
  - Taga (biped)
  - Fukuoka & Kimura (quadruped)
  - ……….

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Legged Locomotion on Irregular Terrain

Conventional Method

- precise model
- trajectory planning
- control

variety of irregularity

Problem

Autonomous Adaptation

?

Why Biological Concepts?

- Animals show marvelous ability of autonomous dynamic adaptation.

- In spite of difference in sensors and actuators, there exist same principles as a physical phenomenon between animals and robots.

Control Methods According to the Speed

[Blickhan & Full:1993], [Full & Koditschek:1999]

	ZMP-based	Limit-Cycle-based	
		Neural System	Musculoskeletal System
good for control of	posture	low / medium speed walking	high speed running
main controller	upper neural system (learning)	lower neural system (CPG + reflexes)	visco-elasticity of muscles (self stabilization)

role of sensor feedback

large ←→ small

Why the role of sensor feedback becomes small in high speed locomotion?

- Kinetic energy is large and dominant.

- In the short cyclic period,
  - the influence of actuator output is small, problem!
  - motion cannot be stabilized by the direct actuation.

- In the short cyclic period,
  - the accumulation of errors is small, advantage!
  - motion can be stabilized by the exchange of stance/swing phases.

    non-linear switching control

Stabilization of Forward Speed

independent of the number of legs

Angular Velocity Control around contact point	Touchdown Angle Control
by ankle joint torque, control the angular velocity of the supporting leg	by touchdown angle, control the forward speed of the next stance phase

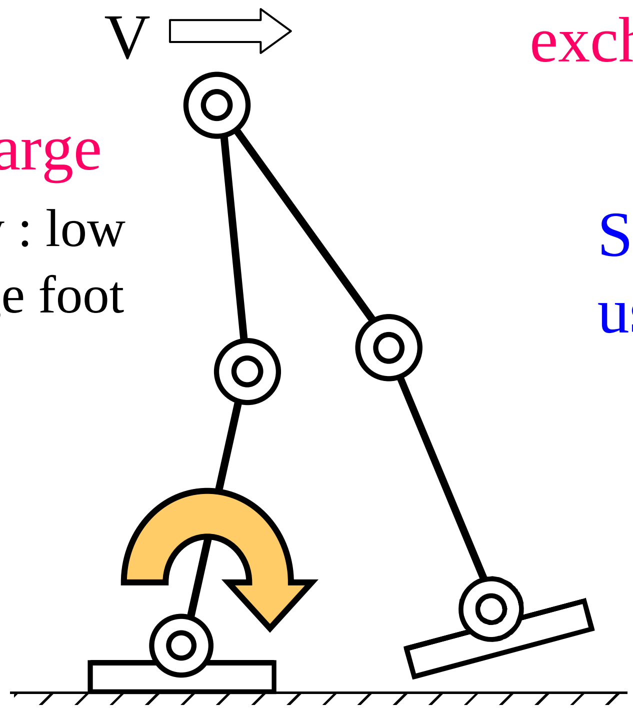
exchange of phases (switching)

Stabilization using the gravity

Torque : Large

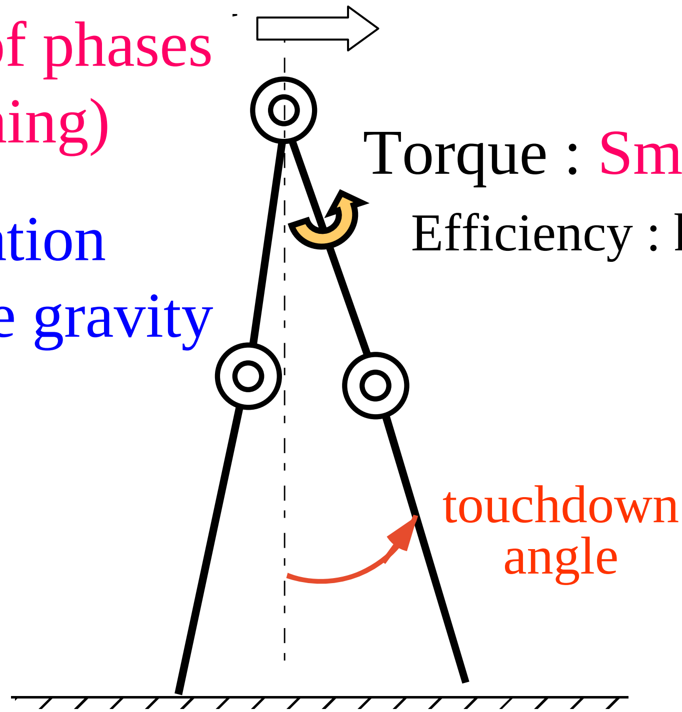
Efficiency : low

Needs large foot

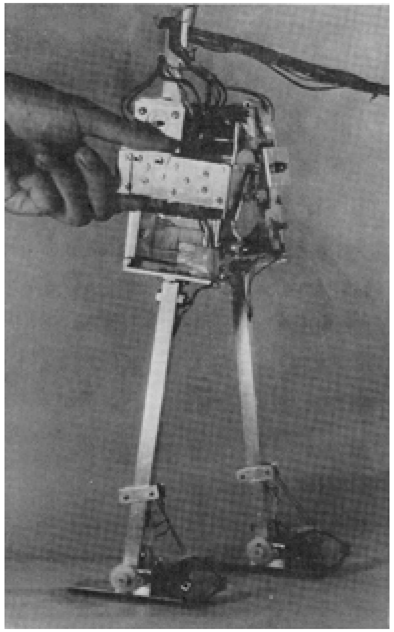


Torque : Small

Efficiency : high



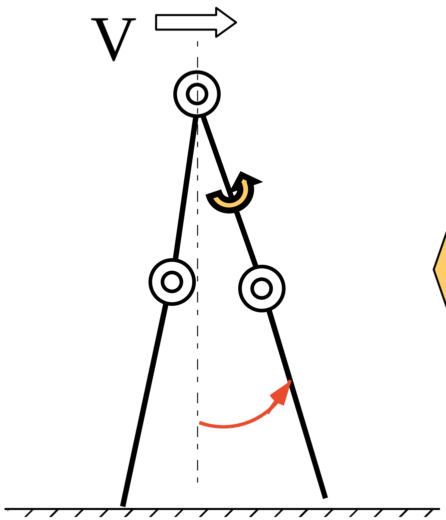
Stabilization of Forward Speed
- Touchdown Angle Control -



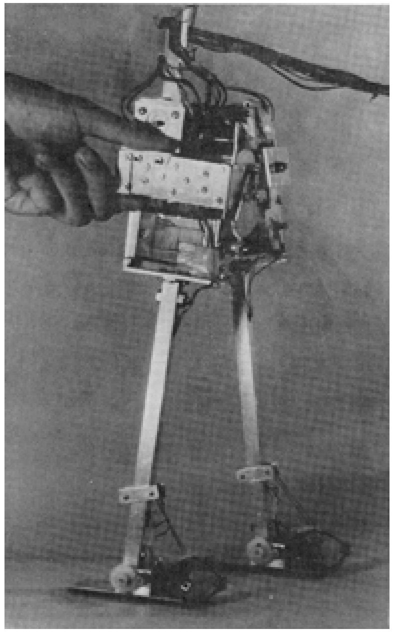
Biper3 [1981]
Miura &
Shimoyama
[IJRR:1984]

like walking on stilts

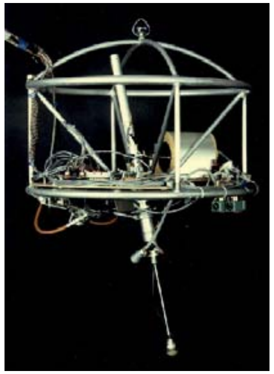
Stabilization of Forward Speed - Touchdown Angle Control -



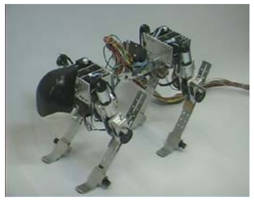
in biological system
stepping reflex



Biper3 [1981]
Miura & Shimoyama
[IJRR:1984]



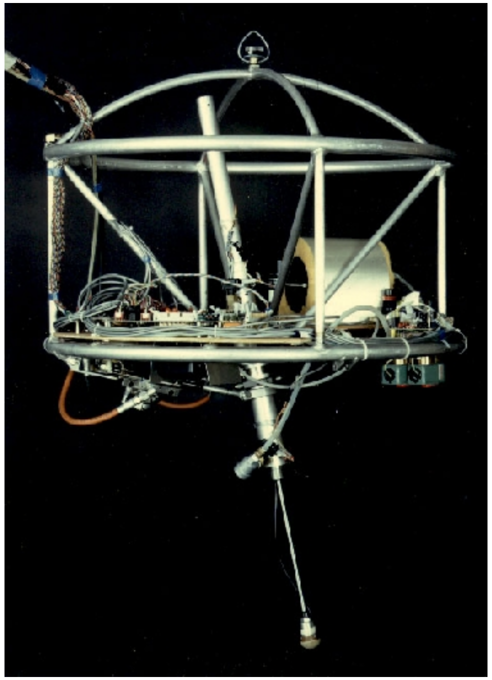
Raibert:1984
the neutral-point foot-placement algorithm

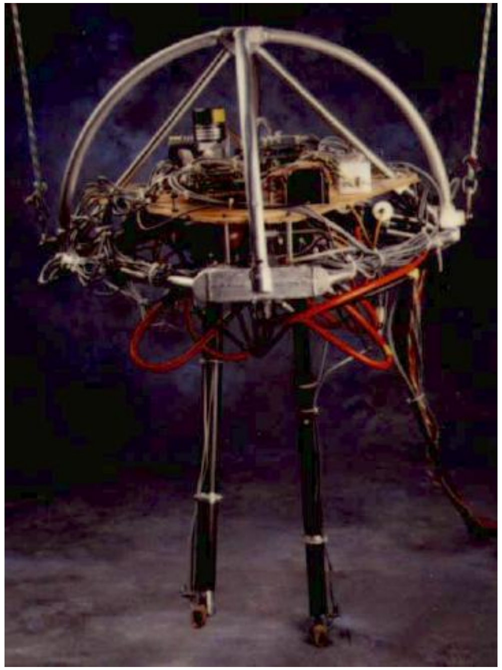


……

Hopping Robots

by Raibert [1983-1992]



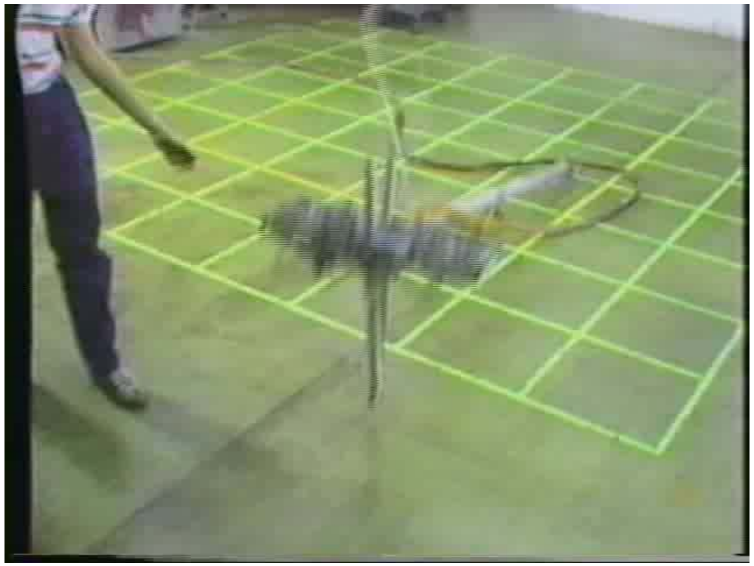


- Point contact
- Air spring
- Light weight leg and the body of large inertia moment
- Touchdown angle control, others

Hopping Robots

Touchdown angle control

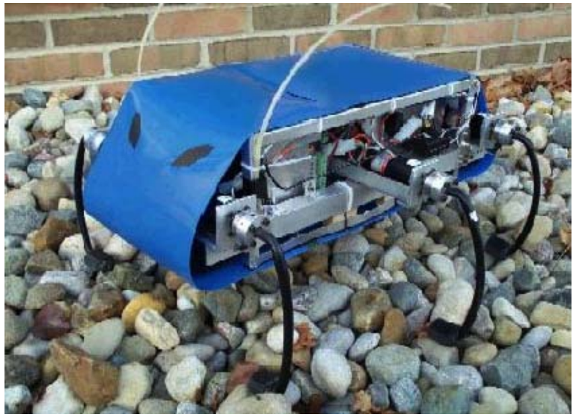
by Raibert [1983-1992]



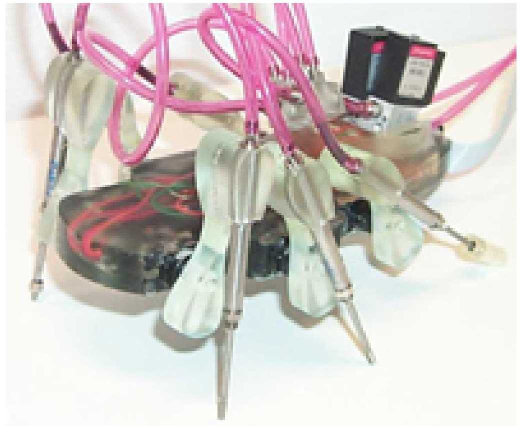
Running on irregular terrain

Quadruped & Hexapod Robots

[SCOUT-II]



[RHex]

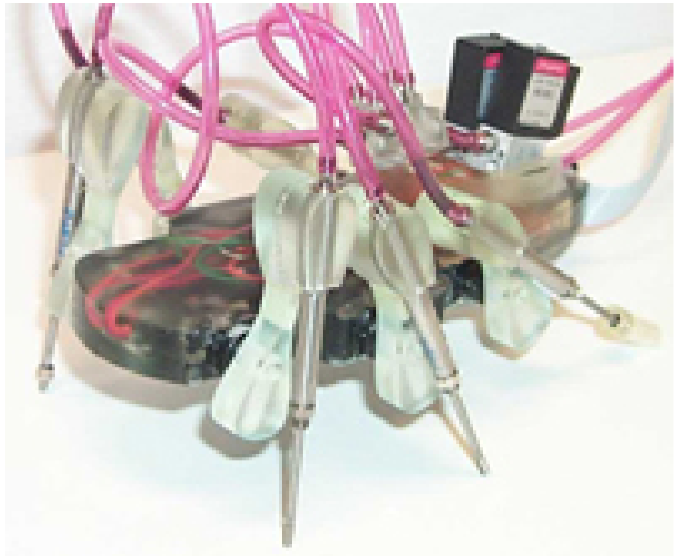


[Sprawlita]

- Point contact
- (Passive) compliant and light weight leg
- Analysis of self stabilization

Hexapod Robots

RHex (2000-)



Sprawlita, … (2000-)

Self stabilization

to stabilize the forward speed without measuring it

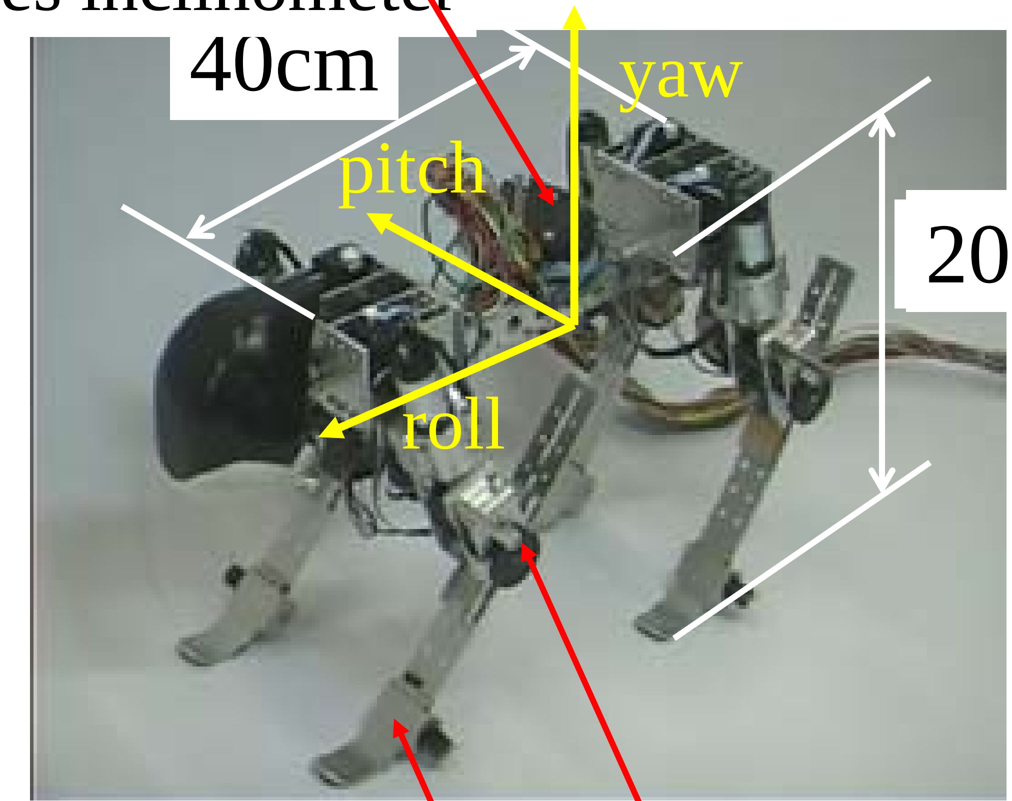
Quadruped Robot: ‘Tekken1’

[2001-2003]

2 axes rate gyro &
2 axes inclinometer

- Weight:3Kg
- Pitch Axis (3 joints)
  Hip & Knee joints: active
  Ankle joint: passive
- Yaw Axis (1 joint)

- Light weight leg
- Small foot
- Small gear ratio: ~16
  viscosity: small
  compliant joint



contact sensor

encoder

Sensor based adaptive walking on irregular terrain

Over Obstacles and Slopes

Characteristics of Legged Robots based on Biological Concepts

- Mechanical design good for
  - medium & high speed locomotion
  - adaptation to irregular terrain

- Short cyclic period : rhythmic motion

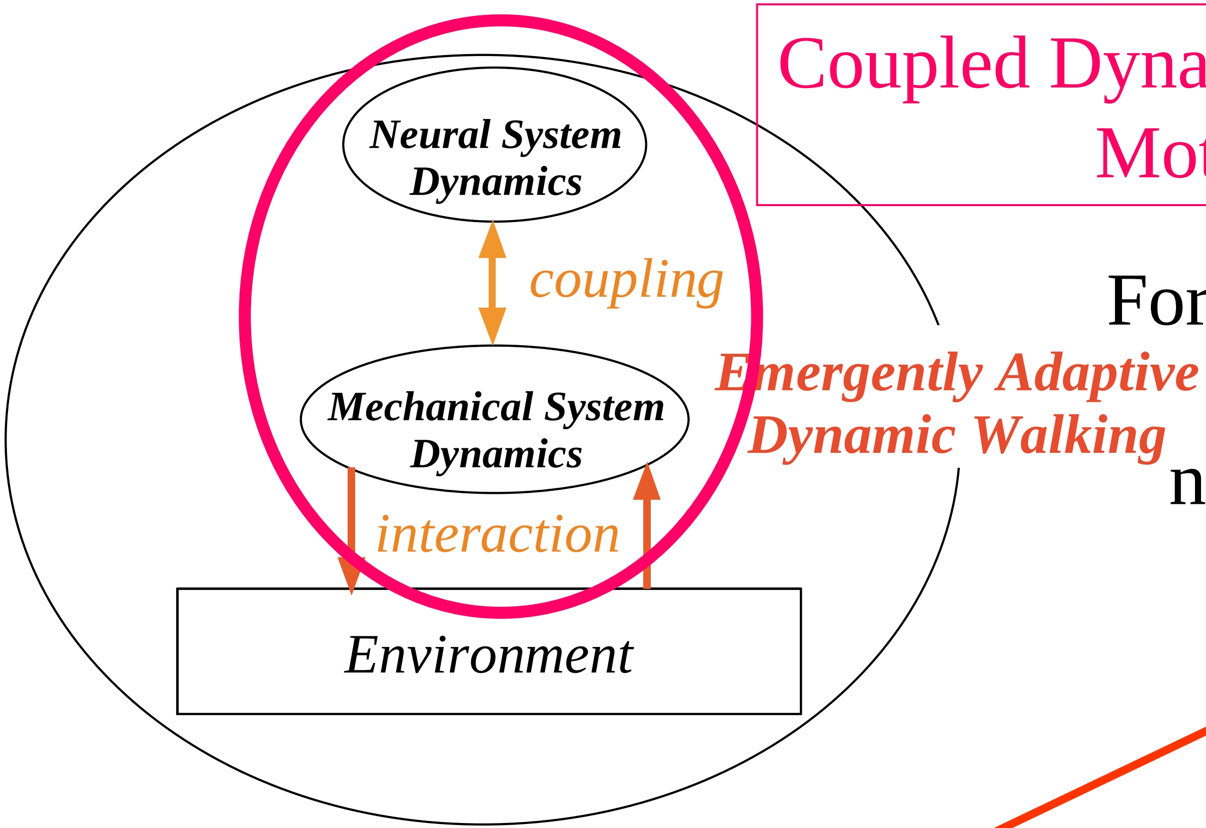
- Complicated trajectory planning and control are not necessary.

- Motion generation and adaptation by single system

Autonomous Adaptive Walking

by Taga[1991]

Coupled Dynamic based Motion Generation



For desirable adaptation, we must construct neural system carefully.

dynamic walking on irregular terrain

physics,
physiology,
biomechanics,
…

Outlines

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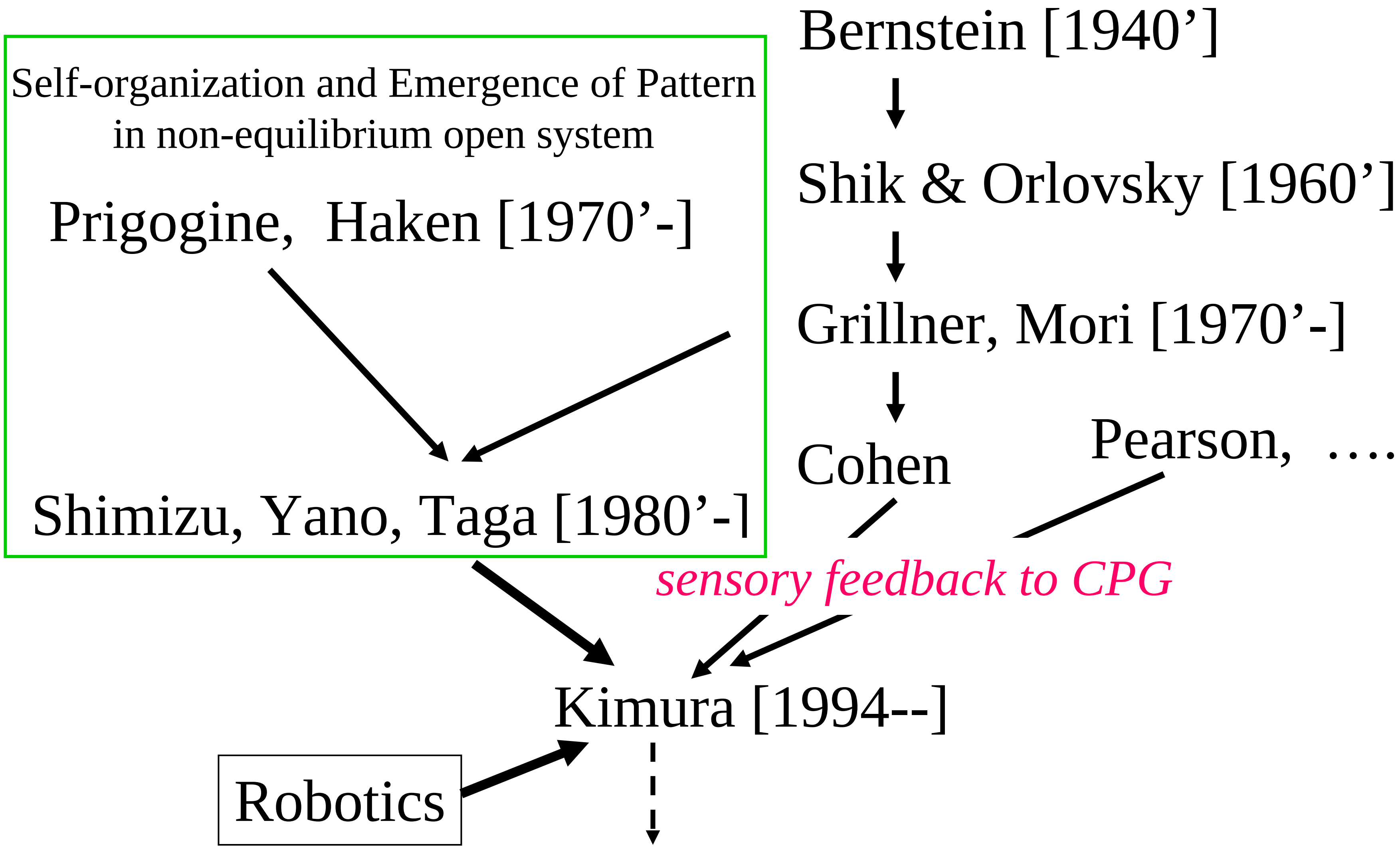
History of Emergingly Adaptive Walking Study

Keywords: Emergence, Embodiment, Entrainment, Synergy



What is Emergence of Pattern?

- "Global pattern (motion)" is generated in the interaction between non-linear dynamic system and environment, even though only "relations between elements" of the system are defined.

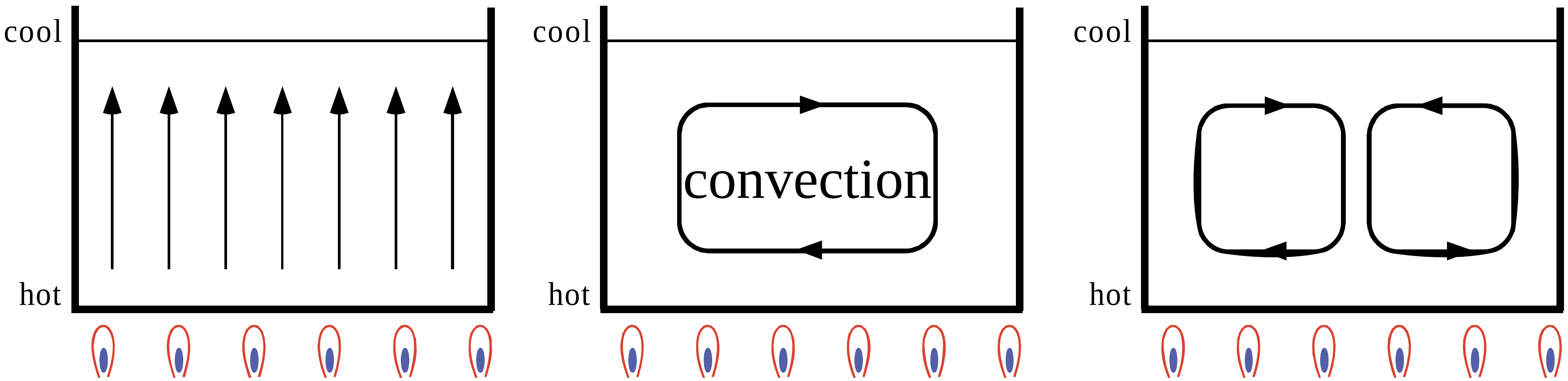
- The non-linear system can always generate the pattern for the change of environment according to its own dynamics.

→ Autonomous adaptation

Emergence of Pattern (1)

non-equilibrium open system

As the result of balance between input energy and consumed energy, structure (pattern) appears.



heat conduction

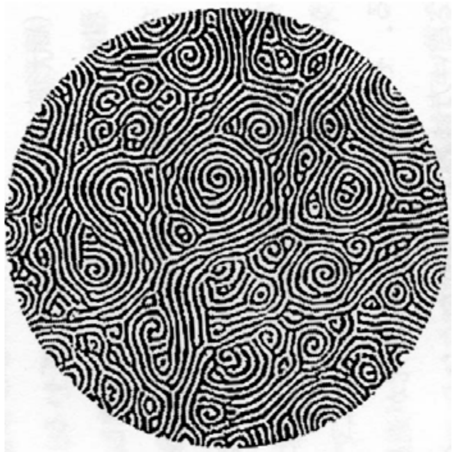
heat transmission

when thermal difference becomes large.

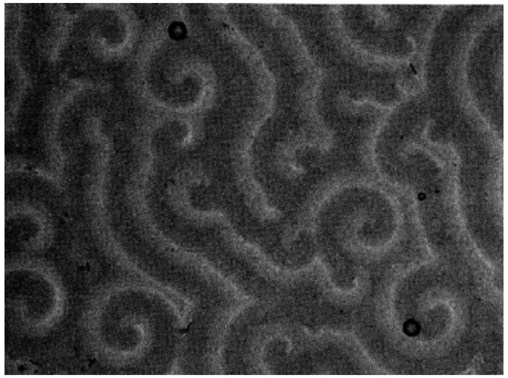
generation of pattern according to boundary condition

Emergence of Pattern (2)

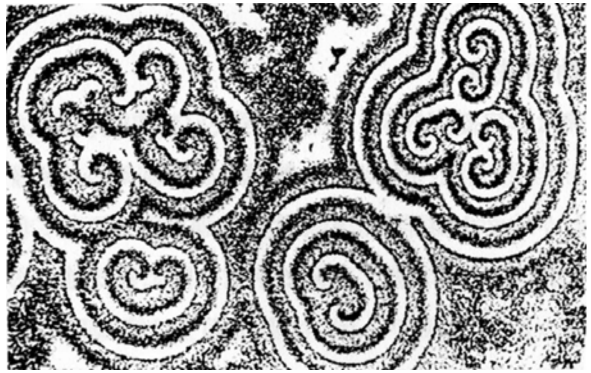
generation of dynamic pattern（spiral wave)
in non-equilibrium open system



Rayleigh & Bernard
convection
in thermohydrodynamic



BZ Chemical Reaction



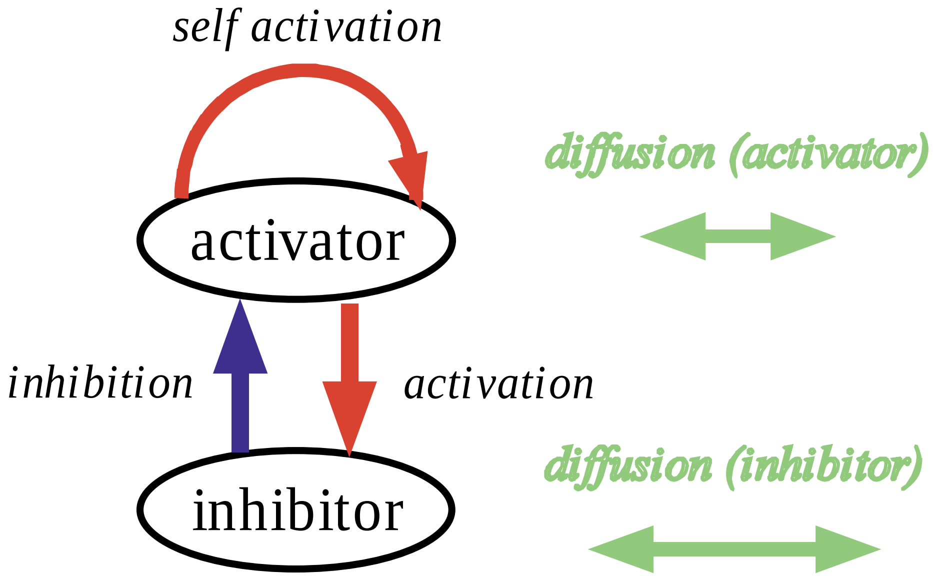
deformable body
of slime mold (fungi)

Common Principles : theory of non-equilibrium open system
Prigogine et al.
“dissipation structure”

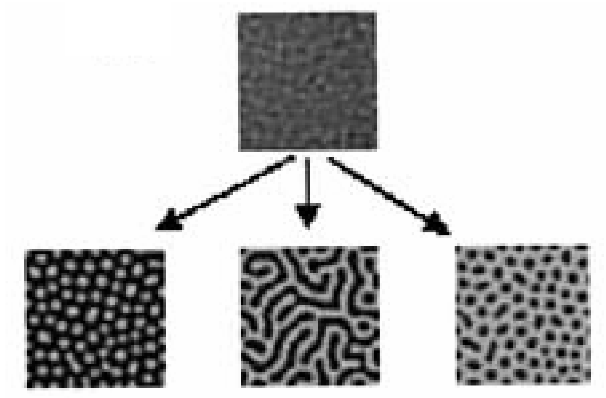
Emergence of Pattern (3)

- Generation of Skin Pattern -

[S.Kondo:Nature95]



Turing's model of reaction-diffusion



Emergence of Pattern (4)

- Passive Dynamic Walking -

(Cornel Univ : 2000)

non-equilibrium open system

← Potential energy

→ Energy loss by collision

Pattern is generated!

- Bifurcation
- Chaotic behavior

History of Emergingly Adaptive Walking Study

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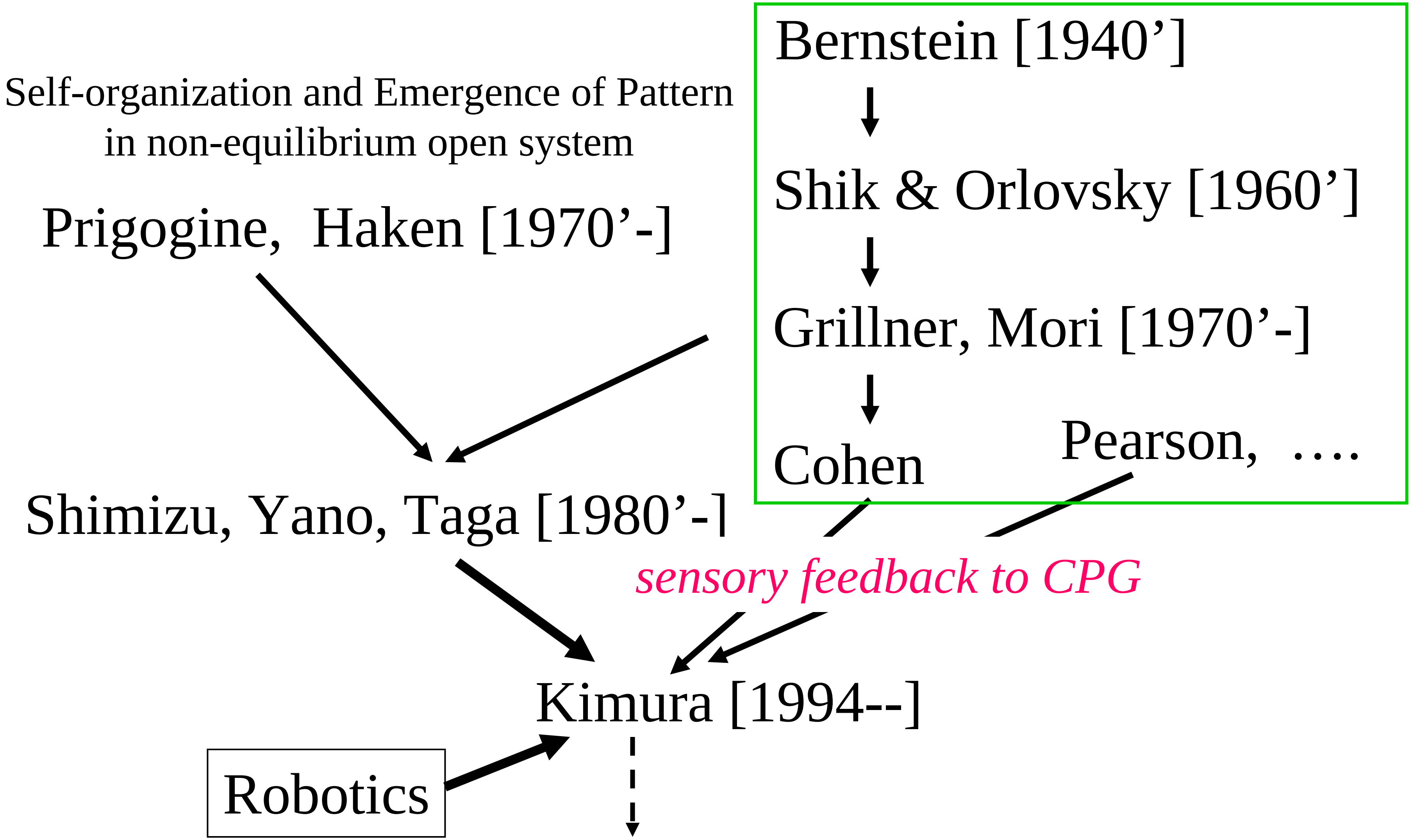


Bernstein Problems in Motor Control

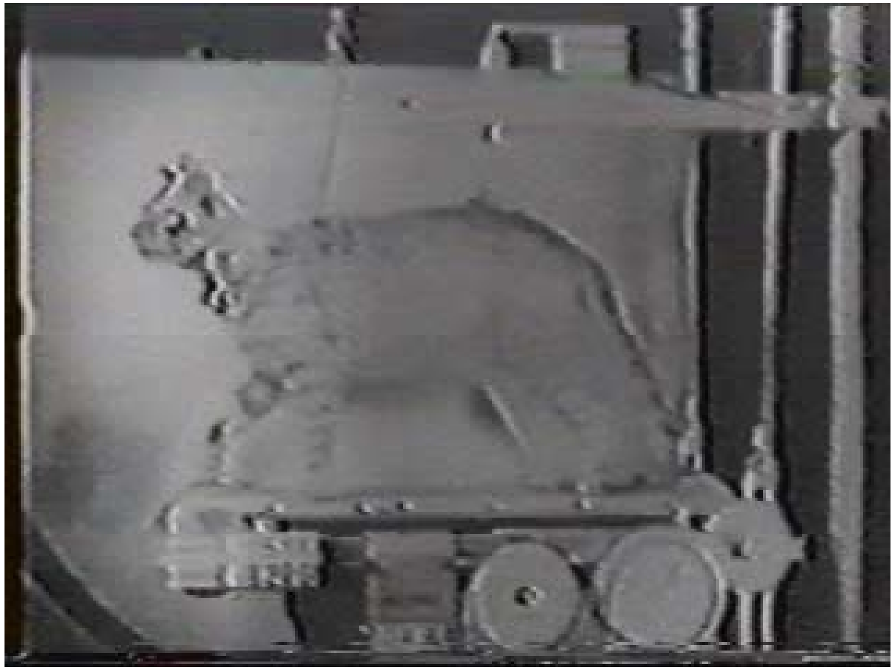
[1940’-]

- Motor redundancy problem
  - synergy
- Context dependency problem
  - selection of appropriate motor pattern

Decerebrate Cat

Motivated by Bernstein Problems

……………………..
[Brown:1939]



……………………..
[Shik & Orlovsky:1960’]
……………………..

The center of generation and adaptation of locomotion is located at the spinal cord.

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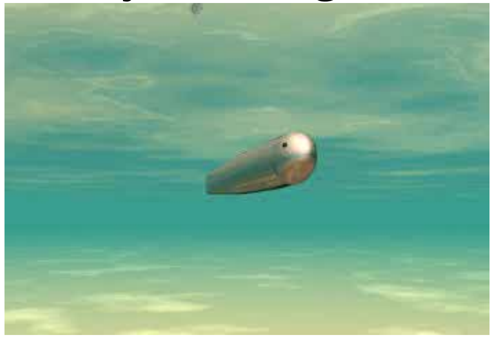
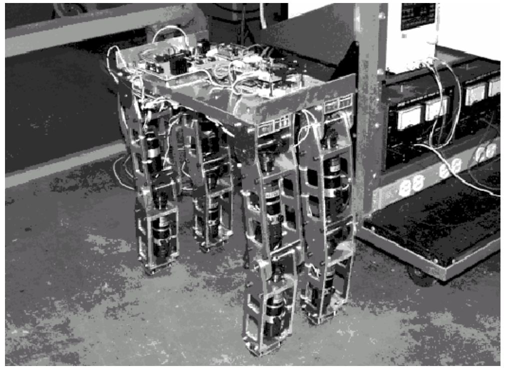
Locomotion Control Using Neural System Model

[by Ekeberg]



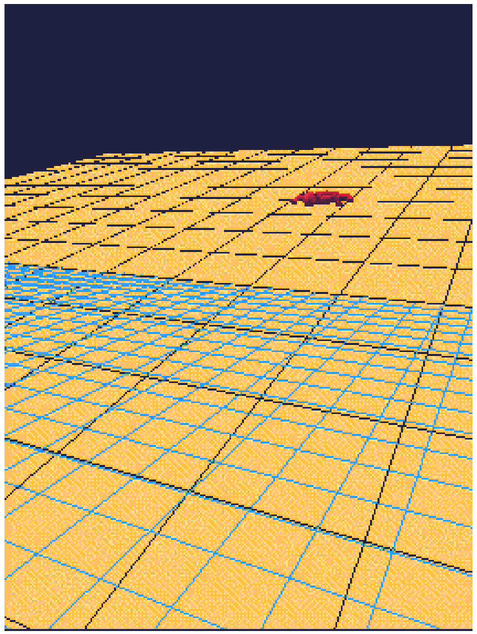
[Northeastern Univ.]

BISAM

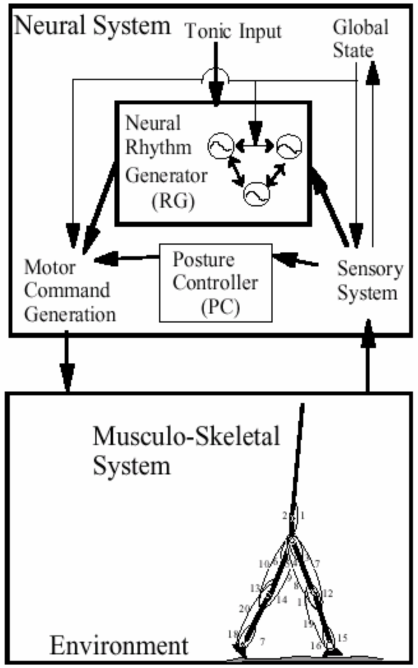


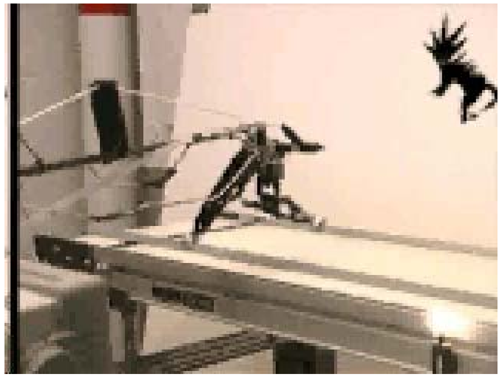
[Kyoto Univ.]

[by Ijspeert]



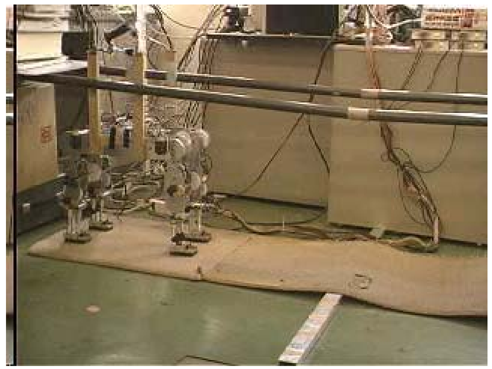
[by Taga]





[Iguana co.]

Patrush[UEC]



What is Neural System Model Control?

- Rhythm
- Phase Difference between Legs

CPGs

- Tuning of Muscle Tone

Reflexes

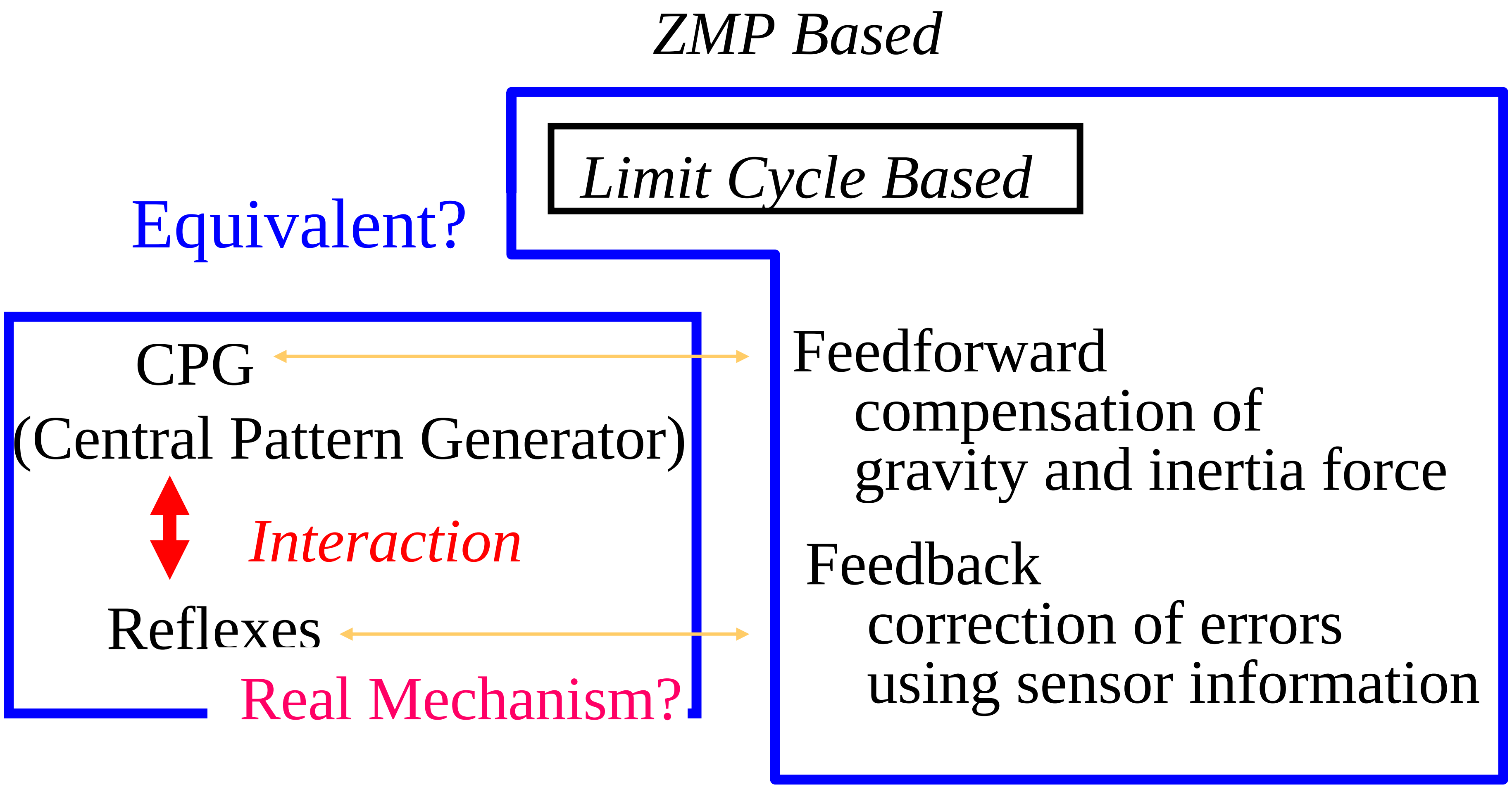
Physiological Experiments Using Cats :

....
S. Mori [1973]
....

Computer Simulation & Robot Experiments

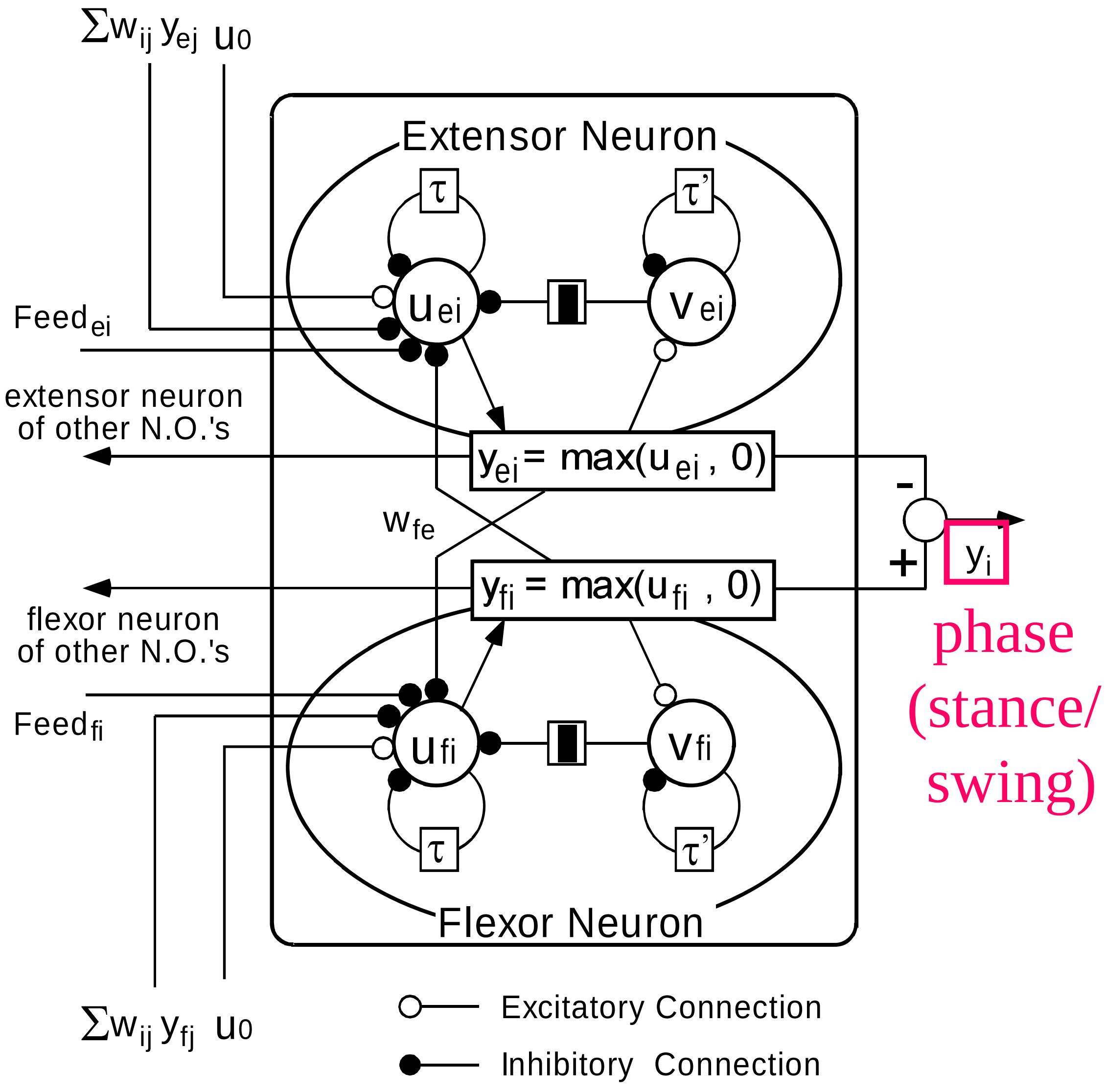
....
Kimura [1994-]
....

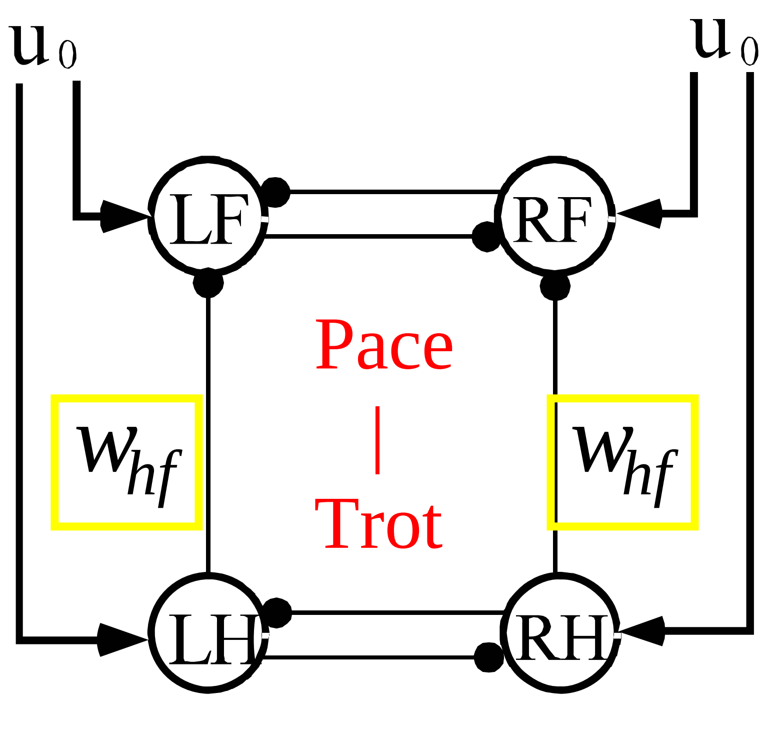
What is Neural System Model Control?



CPG (Central Pattern Generator)

Neural Oscillator by Matsuoka[87] & Taga[91]





$$-1 < w_{hf} < -0.1$$

Neural Oscillator

Matsuoka[87], Taga[91]

time constant

$$\tau\dot{u}_{\{e,f\}i} = -u_{\{e,f\}i} + w_{fe}y_{\{f,e\}i} - \beta v_{\{e,f\}i} + u_{0i} + Feed_{\{e,f\}i} + \sum_{j=1}^{n} w_{ij}y_j$$

$$y_{\{e,f\}i} = \max\left(0, u_{\{e,f\}i}\right)$$

$$\tau'\dot{v}_{\{e,f\}i} = -v_{\{e,f\}i} + y_{\{e,f\}i}$$

joint angle,
body roll angle,
etc.

$u_{\{e,f\}i}$: inner state of the neuron $y_{\{e,f\}i}$: output of the neuron

$v_{\{e,f\}i}$: variable representing the self inhibition

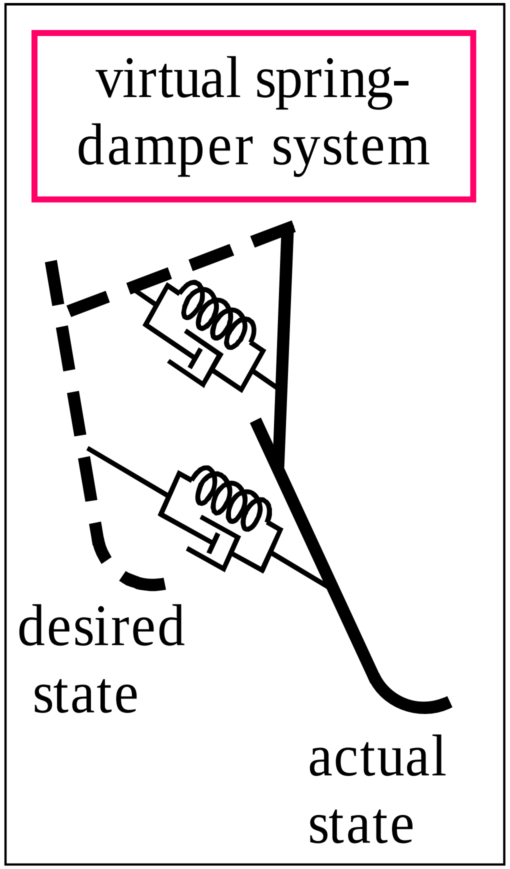
Tuning of Muscle Tone

Joint PD Control as a Tonic Stretch Reflex

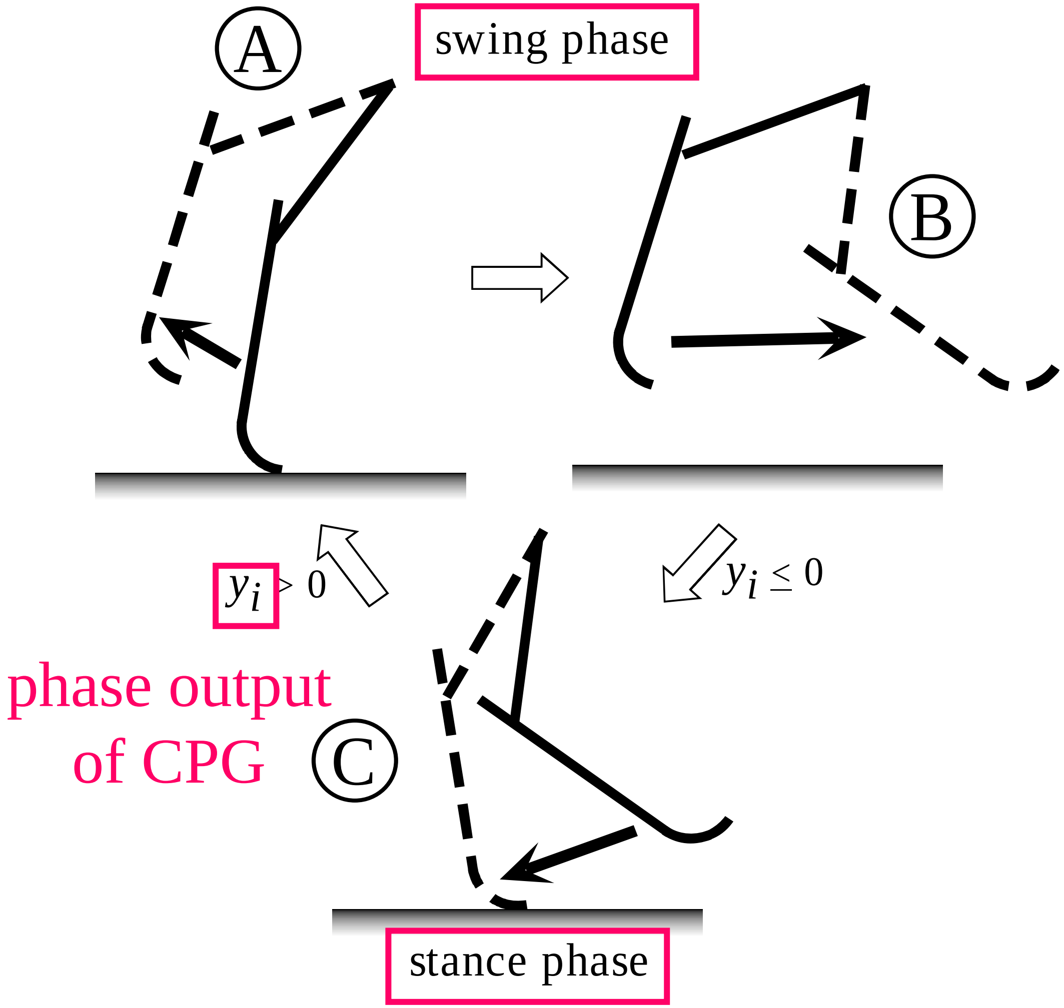
$$trq_{jnt} = -K1_{jnt}\,(\theta^{*}_{jnt} - \theta_{jnt}) - K2\,\dot{\theta}_{jnt}$$

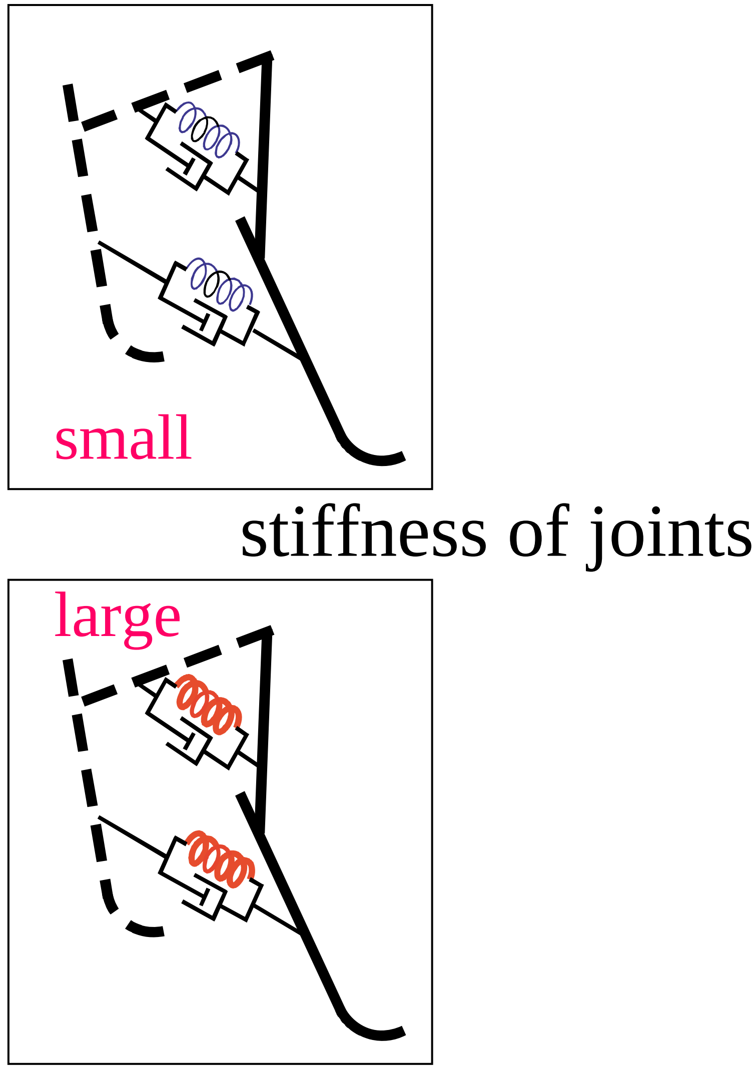
$$\theta^{*}_{jnt} = \begin{cases} \theta^{stance}_{jnt} \\ \theta^{swing}_{jnt} \end{cases}$$

$$K1_{jnt} = \begin{cases} K1^{stance}_{jnt} \\ K1^{swing}_{jnt} \end{cases}$$



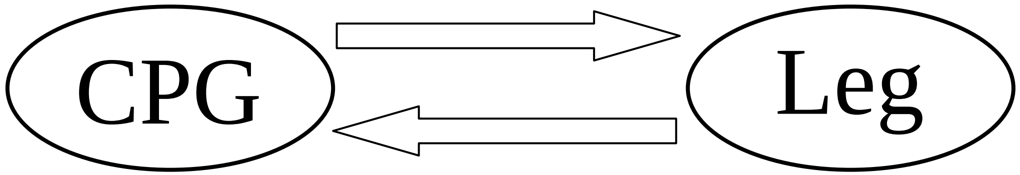
Phases are switched by CPGs



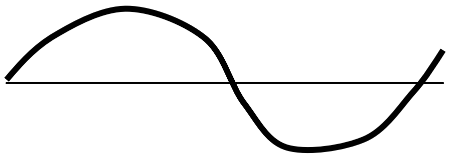


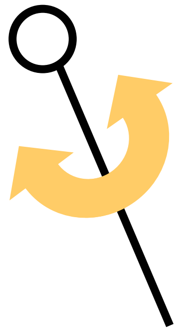
Mutual Entrainment

phase (stance / swing)



hip joint ankle





oscillate with same cyclic period &
fixed phase difference

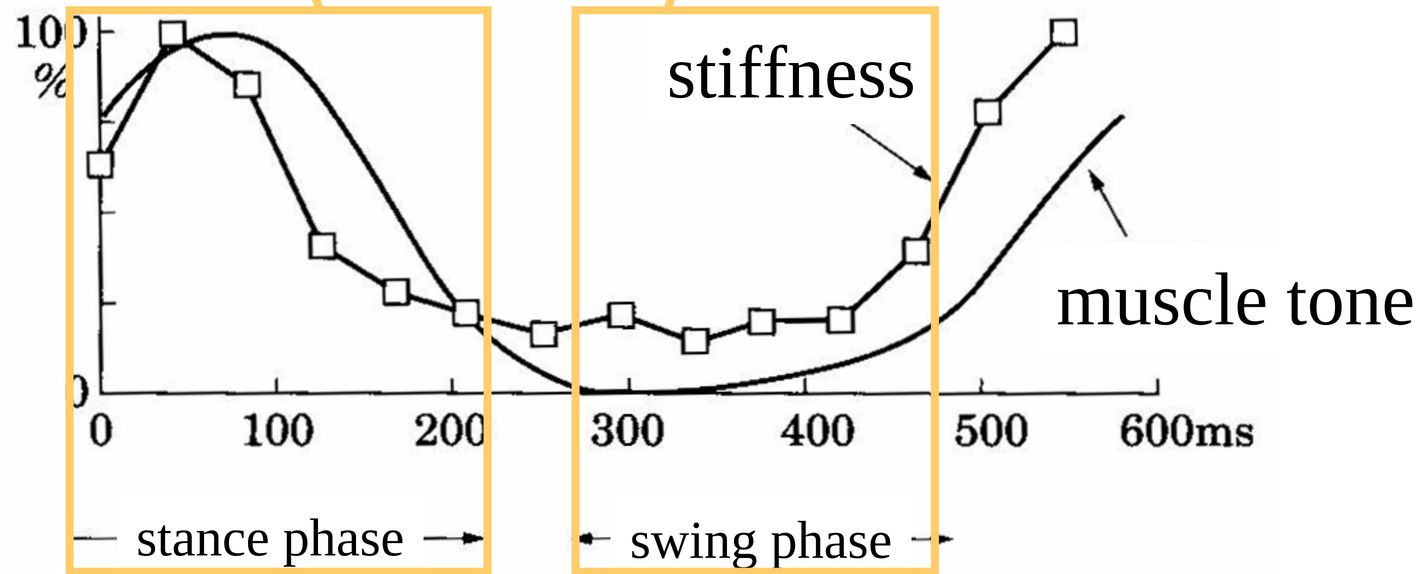
important concepts #2

Change of Stiffness in Stance/Swing Phases

Tekken[2001-]

large in the stance phase
- against the gravity

small in the swing phase
- for irregular terrain
- reduce the impact force



Muscle tone and stiffness of walking cats [Akazawa:1982]

Interaction between CPG and sensory feedback

reflexes, responses : CPGs' phase dependent

- **Tuning of Muscle Tone** (Joint PD Controller)

pure reflex
- •torque output
- •sensory feedback → reflex *delayed*

- **Rhythm Generation** (CPG: Central Pattern Generator)

tunable reflex
- •phase (stance/swing) output
- •sensory feedback → response *quickly*

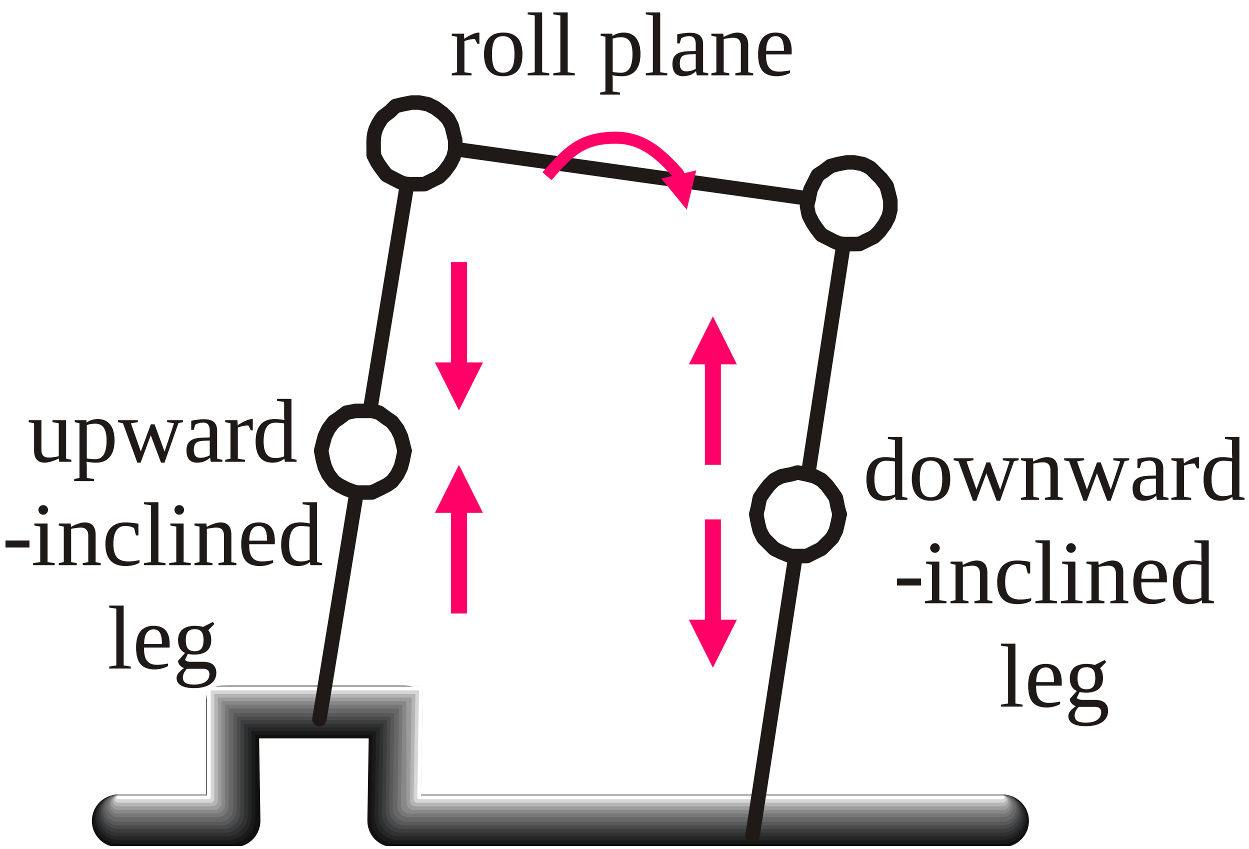
CPGs' phase modulation

Reflexes and Responses

	sensed value or event	activated on
flexor reflex	collision with obstacle	sw
stepping reflex	forward speed	sw
vestibulospinal reflex/response	body pitch angle	sp
vestibular reflex/response	body roll angle	sp & sw
sideway stepping reflex	body roll angle	sw
re-stepping reflex/response	loss of ground contact	sw

sp : supporting leg
sw : swinging leg

Vestibular Reflex for Rolling



Vestibular Response for Rolling

$$Feed_{e \bullet roll} = \delta(leg) \times k_{tlrr} \times (body\ roll\ angle)$$

$$Feed_{f \bullet roll} = -Feed_{e \bullet roll}$$

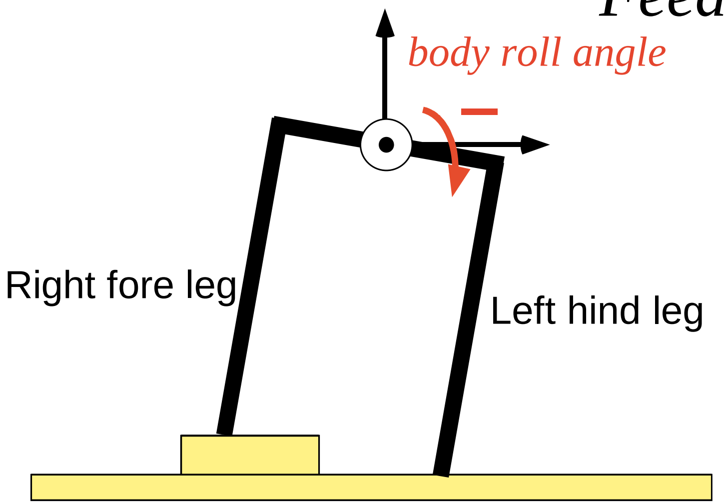
$$\delta(leg) = \begin{cases} 1, & \text{if } leg \text{ is a right leg} \\ -1, & \text{if } leg \text{ is a left leg} \end{cases}$$

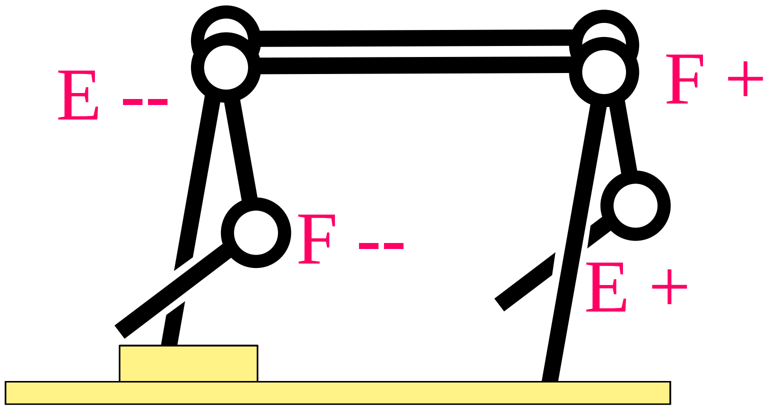
Vestibular Response for Rolling

$$Feed_{e.roll} = \delta(leg) \times k_{roll} \times \underline{(body\ roll\ angle)}$$

$$Feed_{f.roll} = -Feed_{e.roll}$$

< 0





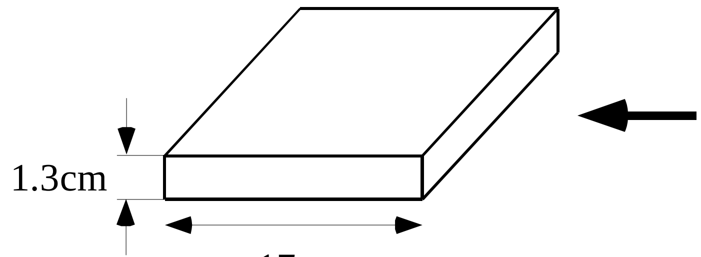
Right fore leg	E -- F +	Right hind leg	E -- F +
Left fore leg	E + F --	Left Hind leg	E + F --

Roll Motion Feedback to CPG

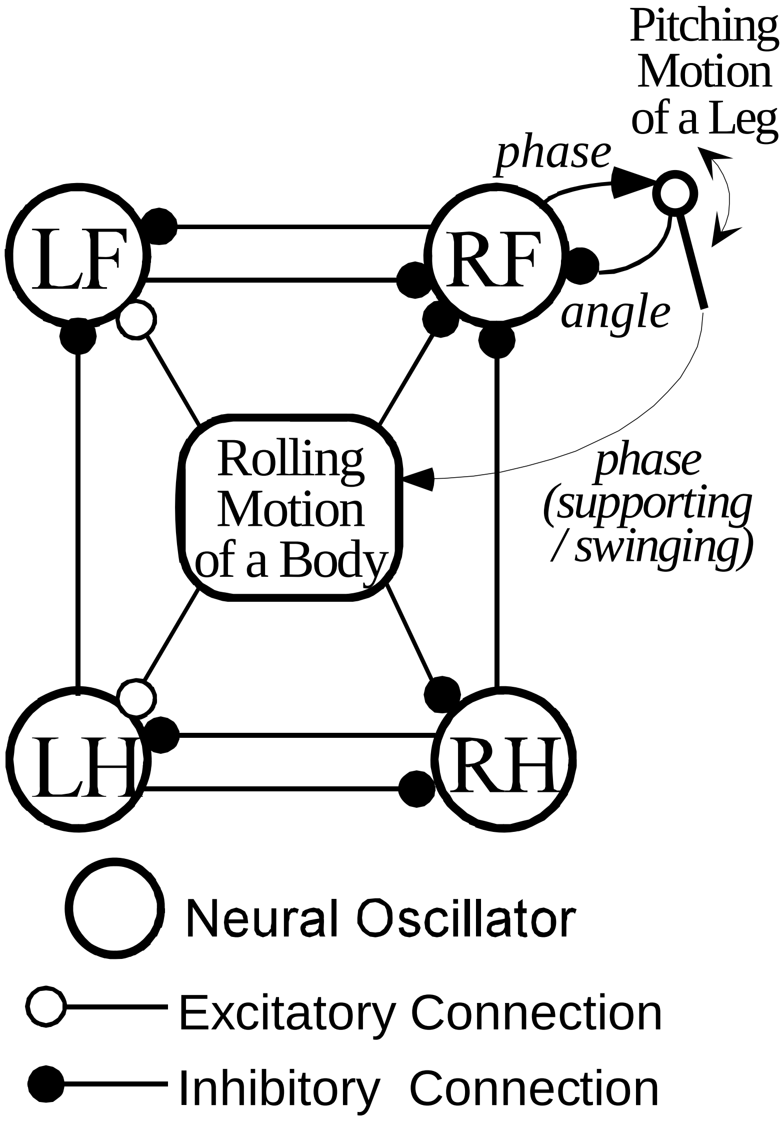
Without

With

T = 0.3 sec.



Rolling Motion as Standard of Rhythm



Rolling motion feedback to CPG

↓

Stabilizing a gait

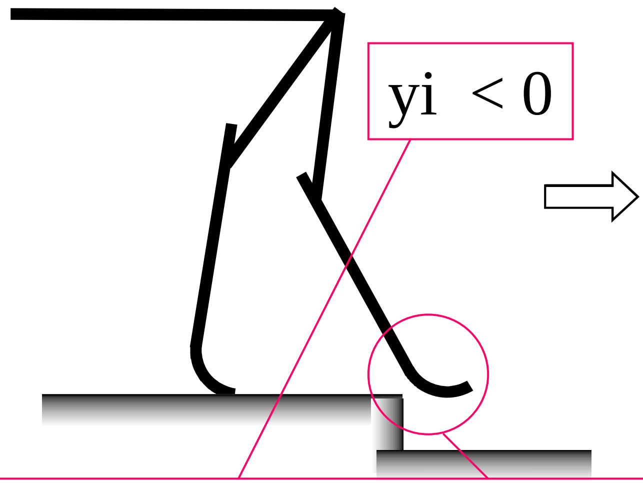
Adjusting phases of CPGs

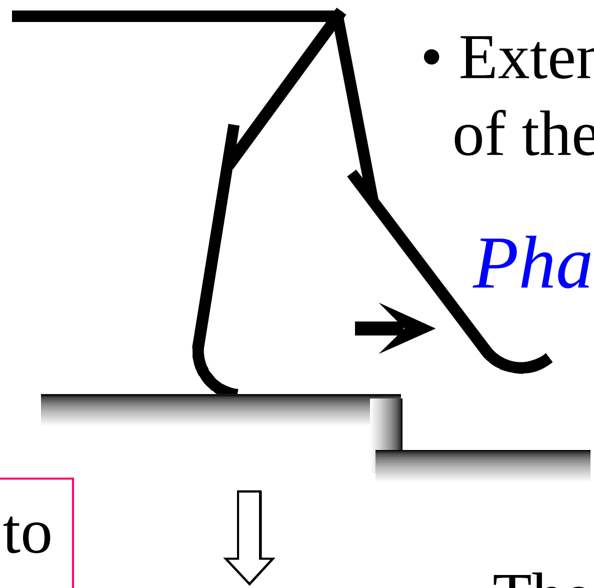
Reflexes and Responses

	sensed value or event	activated on
flexor reflex	collision with obstacle	sw
stepping reflex	forward speed	sw
vestibulospinal reflex/response	body pitch angle	sp
vestibular reflex/response	body roll angle	sp & sw
sideway stepping reflex	body roll angle	sw
re-stepping reflex/response	loss of ground contact	sw

sp : supporting leg
sw : swinging leg

Re-stepping Response
- in case of loss of ground support -

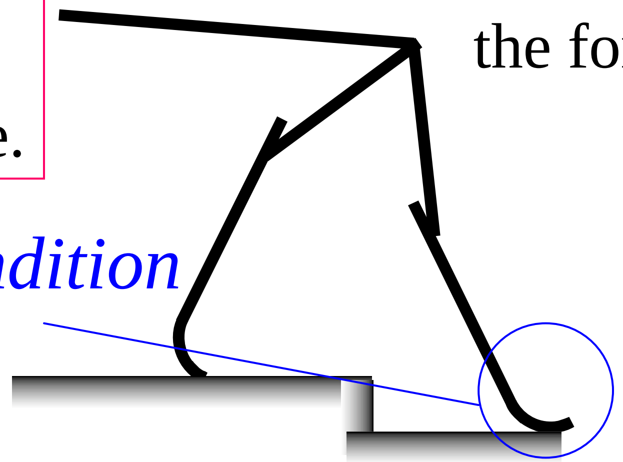




- Extend the swing phase of the CPG

Phase modification

- The phase of a CPG moved to the stance phase.
- The contact of the leg is not detected within the fixed time.



- The leg lands on the forwarder position.

Adjustment of initial condition of a stance phase

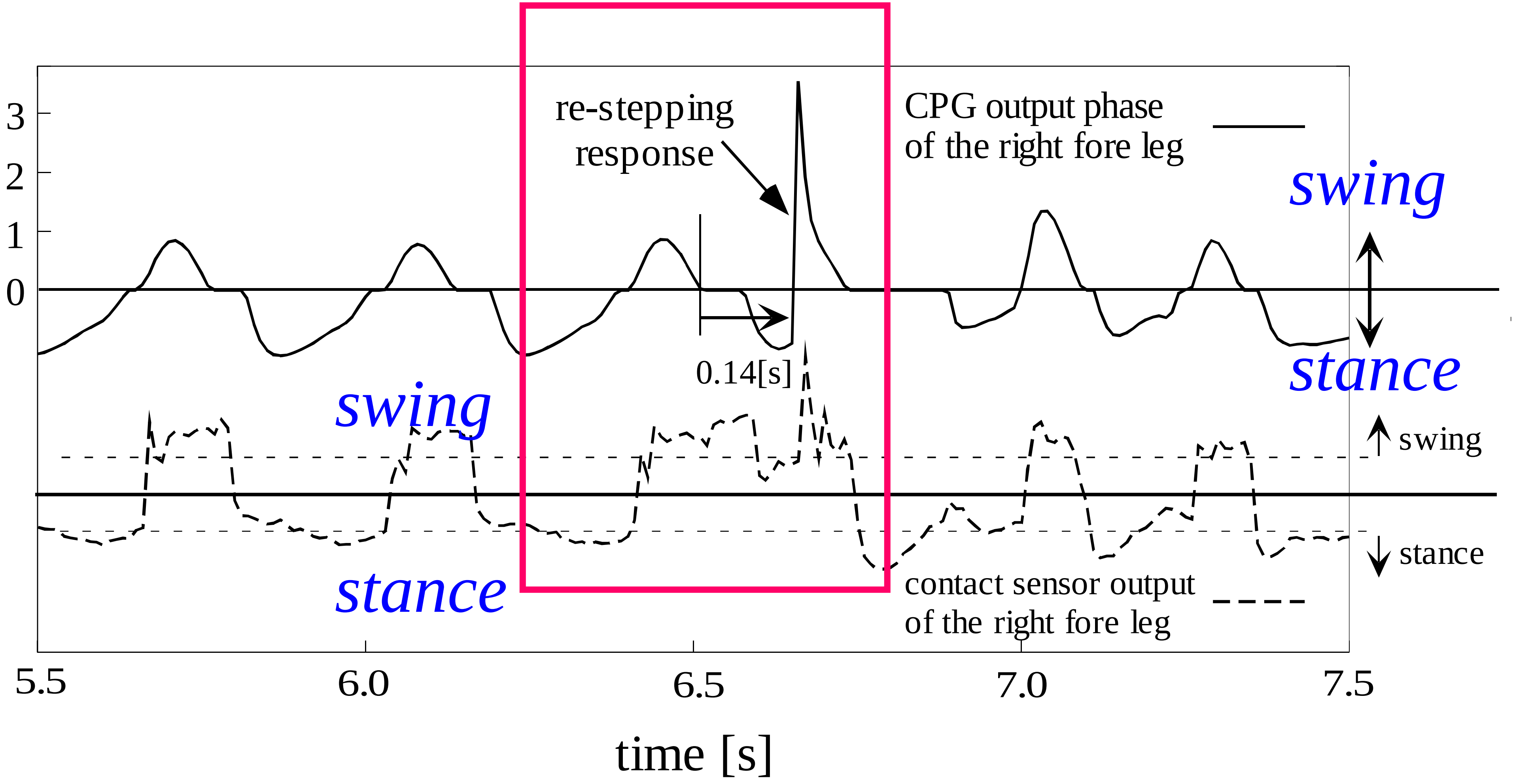
[Pearson et al: 1994]

Re-stepping Response Walking
- down a step 7cm in height -

without

with

Re-stepping Response Walking - down a step 7cm in height -

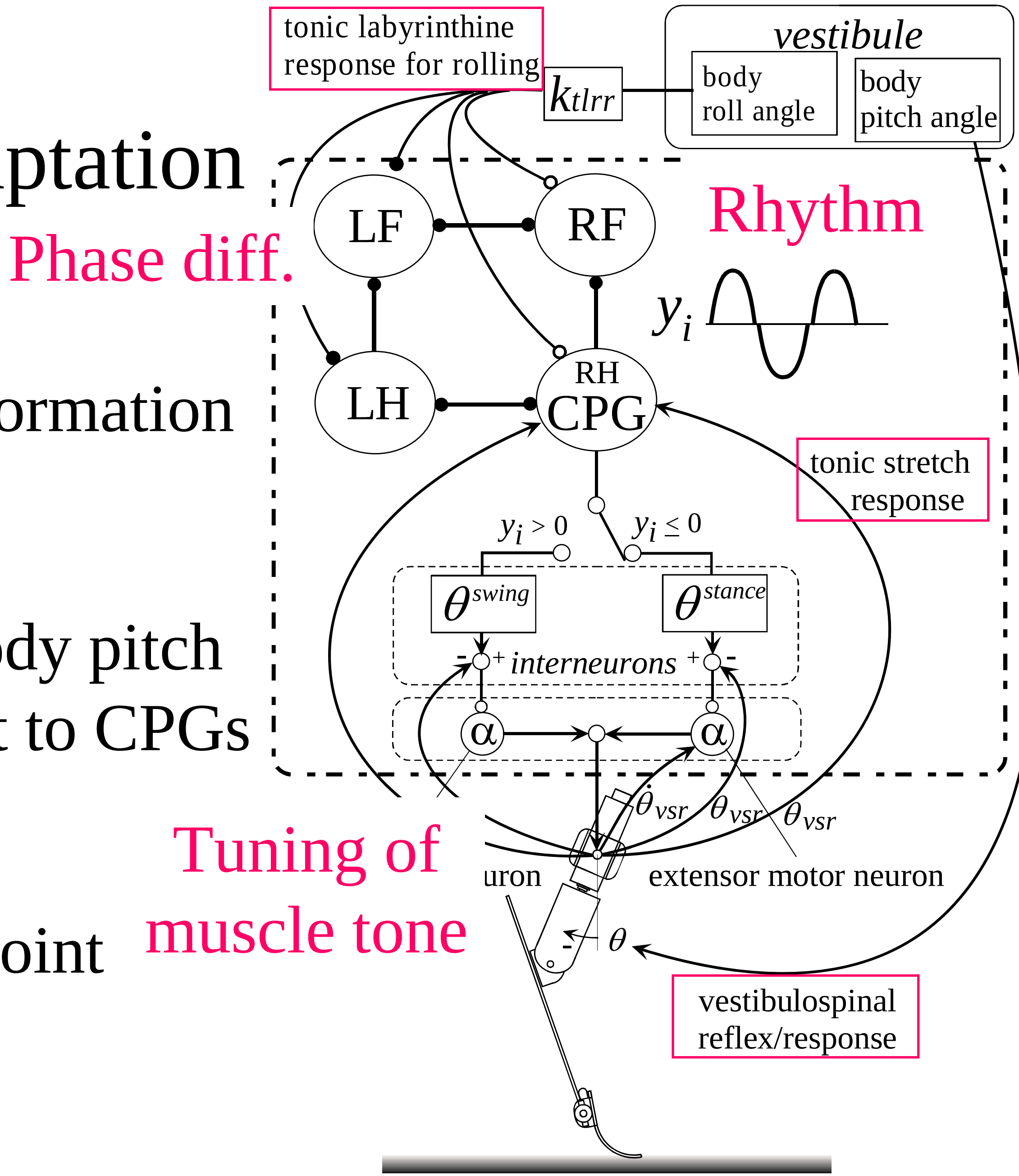


Motion Generation & Adaptation

CPG outputs phase information (stance/swing phase).

Hip joint angle, the body pitch and roll angle are input to CPGs as responses.

PD controller outputs joint torque as reflexes.



Adaptive Walking Using a Neural System Model

Over an obstacle of 20% relative height to a leg

Over pebbles

The values of all parameters are fixed for unknown terrain of medium degree of irregularity.

Tekken2
- self-contained (power autonomous) -

on scattered grasses and pebbles 0.5 m/s

Bernstein Problems in Tekken

- Motor redundancy problem
  - Virtual spring-damper system (PD controller)
- Context dependency problem
  - CPG phase switches PD controller.
  - CPG phase switches reflexes.
  - CPG phase results in gait patterns.
  - CPG is the center of motion integration at the low level.

Outlines

- Legged locomotion control methods
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- Adaptive running of a quadruped robot
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Walking and Running of a Single Robot

no spring → huge energy loss

Tekken-1
Running in a bound gait [2002]
approx. 1 m/s

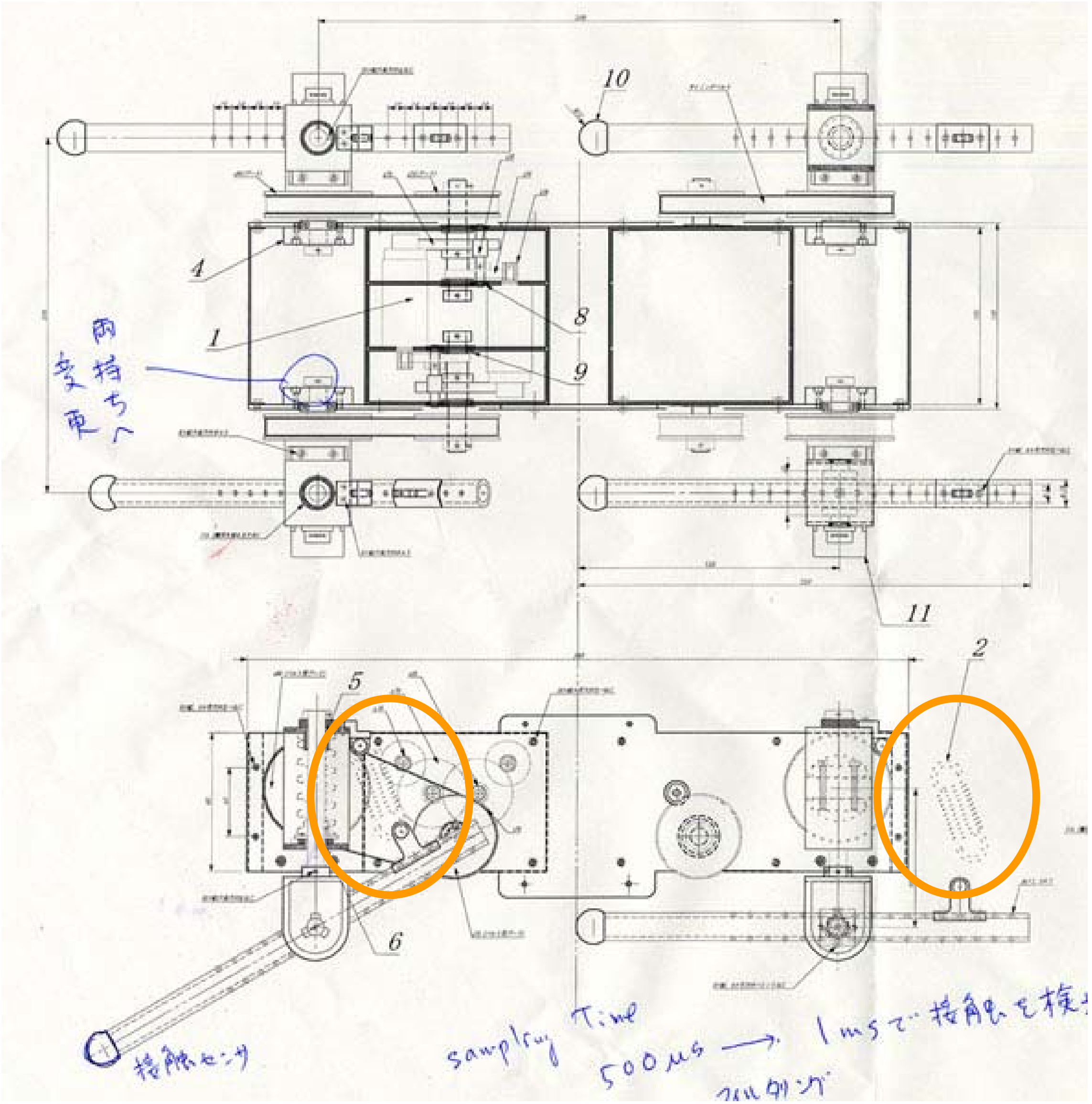
QRIO by Sony
Jogging [2004]

Mechanically Variable Stiffness of Joints - in order to increase adaptability and efficiency -

• Switch between	a stance phase	and	a swing phase
• Switch between	running	and	walking
	large		small

Not yet

Quadruped Running Robot “Rush”



under construction

- 4 DC motors at hip joints
- passive knee joint with spring
- design to suppress the collision impact to upper links and a body

Adaptive Running in a Bound Gait

- Generation of running in a bound gait from standing
  - Energy input
  - Gait generation
- Adaptive running on irregular terrain

Do we need the rhythm generator for running?

No!
for steady running
(spring-mass system)

Yes?
for transitional running
the rhythm generator may help

Ideas

[Zhang et al.:ICRA05]

- Use rhythm generator and torque generator

  Fukuoka & Kimura et al., (1998-2004)

- Consider fixed points of quasi-passive running

  Koditschek et al., Buehler et al, Cham et al.,
  Hyon et al., Zhang et al., ………………. (2000-2004)

- Use DFC (delayed feedback control) to make motion converge to a fixed point

  Osuka et al., Hyon et al., ….. (2002-2004)

Delayed Feedback Control

Discrete Dynamical System

$$\boldsymbol{x}[n+1] = \boldsymbol{\mathcal{F}}(\boldsymbol{x}[n], \boldsymbol{u}[n])$$

$$\boxed{\boldsymbol{y}[n]} = \boldsymbol{\mathcal{G}}(\boldsymbol{x}[n])$$

energy of the system

DFC (Delayed Feedback Control)

$$\boldsymbol{u}[n] = \underline{\boldsymbol{\mathcal{K}}}(\boldsymbol{y}[n] - \boldsymbol{y}[n-1])$$

gain

Ideas

[Zhang et al.:ICRA05]

- Use rhythm generator and torque generator

  Fukuoka & Kimura et al., (1998-2004)

- Consider fixed points of quasi-passive running

  Koditschek et al., Buehler et al, Cham et al.,
  Hyon et al., Zhang et al., ………………. (2000-2004)

- Use DFC (delayed feedback control) to make motion converge to a fixed point

  Osuka et al., Hyon et al., ….. (2002-2004)

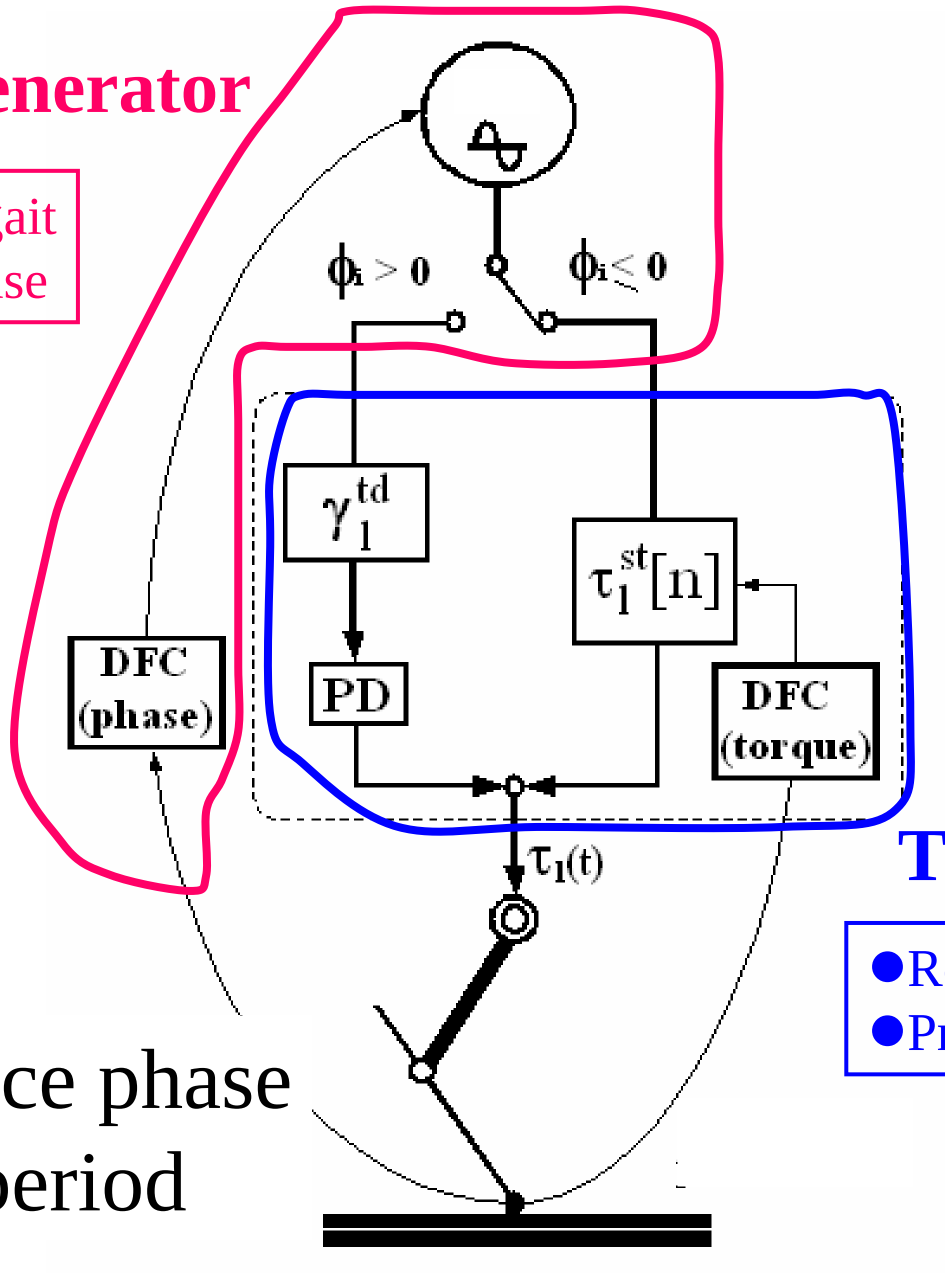
- Use not energy but stance phase period as sensor information

  Cham et al., (2002)

Generator & Controller

Rhythm Generator

- Generate gait
- Adjust phase



Torque Generator

- Remain touchdown angle
- Provide energy input

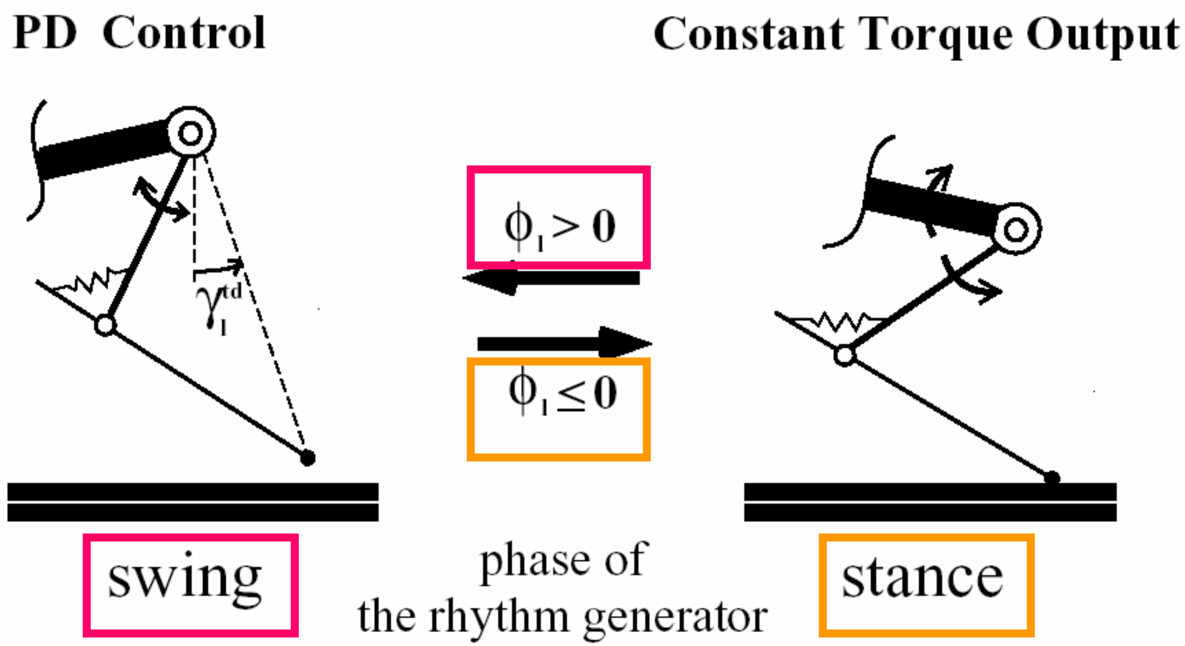
stance phase period

Rhythm Generator

$$\phi_l = \sin(\omega_l[n]t + \psi_l) + \phi_{0l}, \quad \omega_l[n] = \frac{2\pi}{T_l[n]}$$

- ψ_l: initial phase
- $\omega_l[n]$: angular frequency
- ϕ_l: phase of each leg
- ϕ_{0l}: offset (duty factor)
- $T_l[n]$: cyclic period

calculated by DFC



Torque Generator

Depending on the leg phase generated by the rhythm generator, different control actions are assigned.

- $\phi_l > 0$ **Swing phase: PD control**

$$\tau_l(t) = -K_p(\gamma_l - \gamma_l^{td}) - K_d\dot{\gamma}_l$$

γ_l^{td} → **desired touchdown angle**

- $\phi_l \leq 0$ **Stance phase: constant torque**

$$\tau_l(t) = \boxed{\tau_l^{st}[n]}$$

$\tau_l^{st}[n]$: calculated by DFC

Proposed Delayed Feedback Control

stance phase period $t_f^{st}[n]$ $t_h^{st}[n]$

Measured by contact sensors with practical accuracy

Cyclic Period DFC

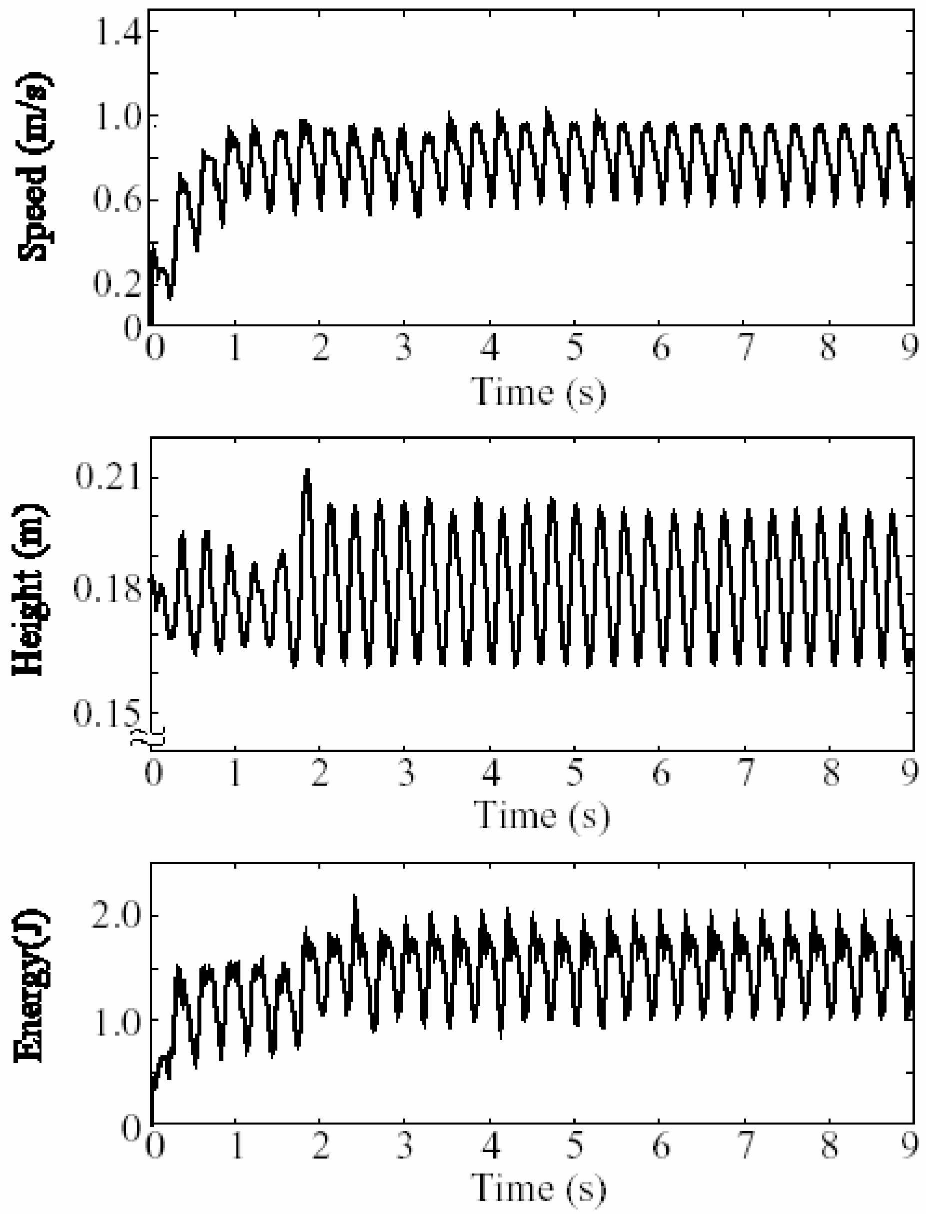
$$T_l[n+1] = T_l[n] - K_{DF \cdot T}(t_l^{st}[n] - t_l^{st}[n-1])$$

Torque DFC

$$\tau_l^{st}[n+1] = \tau_l^{st}[n] - \delta(l) K_{DF \cdot \tau}(t_l^{st}[n] - t_l^{st}[n-1])$$

$$\delta(l) = \begin{cases} -1, & l = f : foreleg \\ 1, & l = h : hindleg \end{cases}$$

Transition from Standing to Steady Running

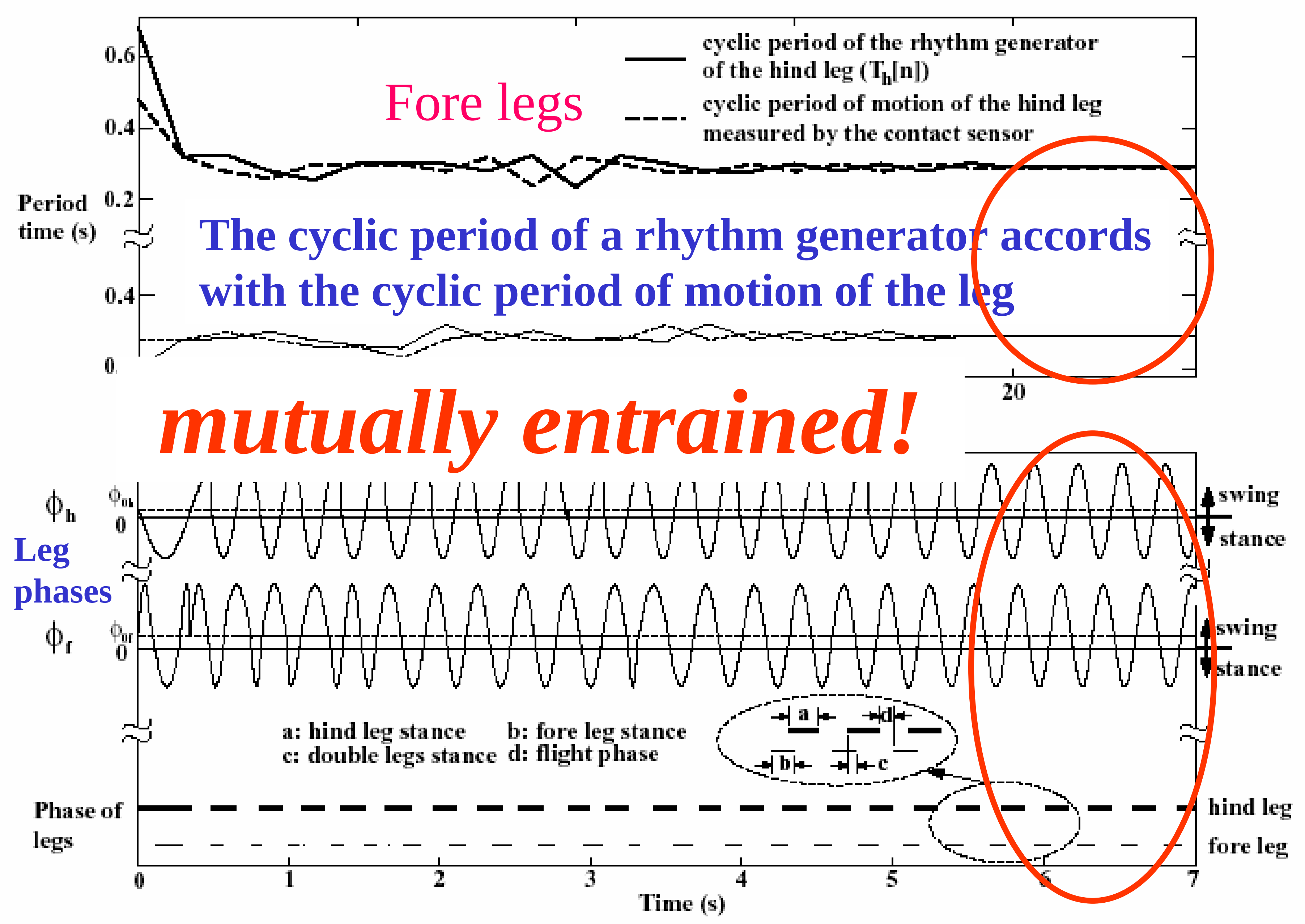


×3 slow

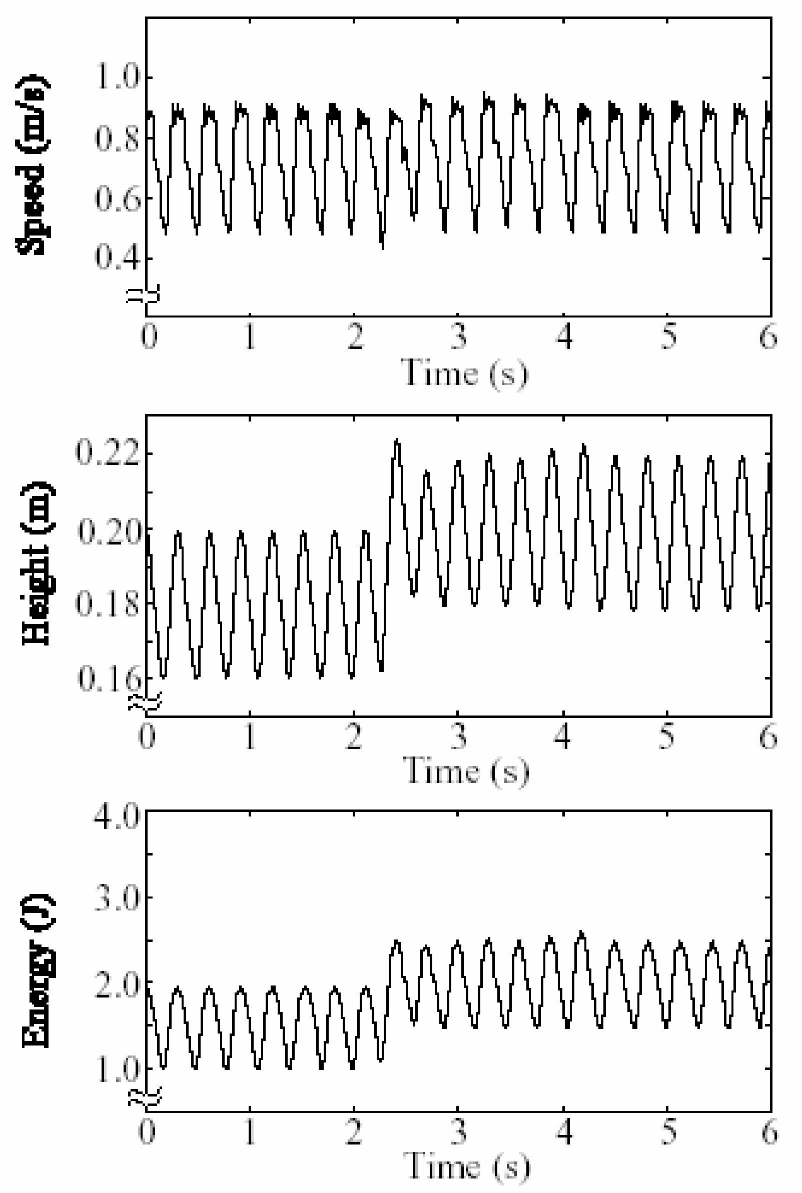
Result:

The apex height and forward speed in the steady state are similar to the state of <u>the fixed point of quasi-passive running</u>

Generating the Bounding Gait



Anti-disturbance Capability
-Running Up a Small Step with DFC-



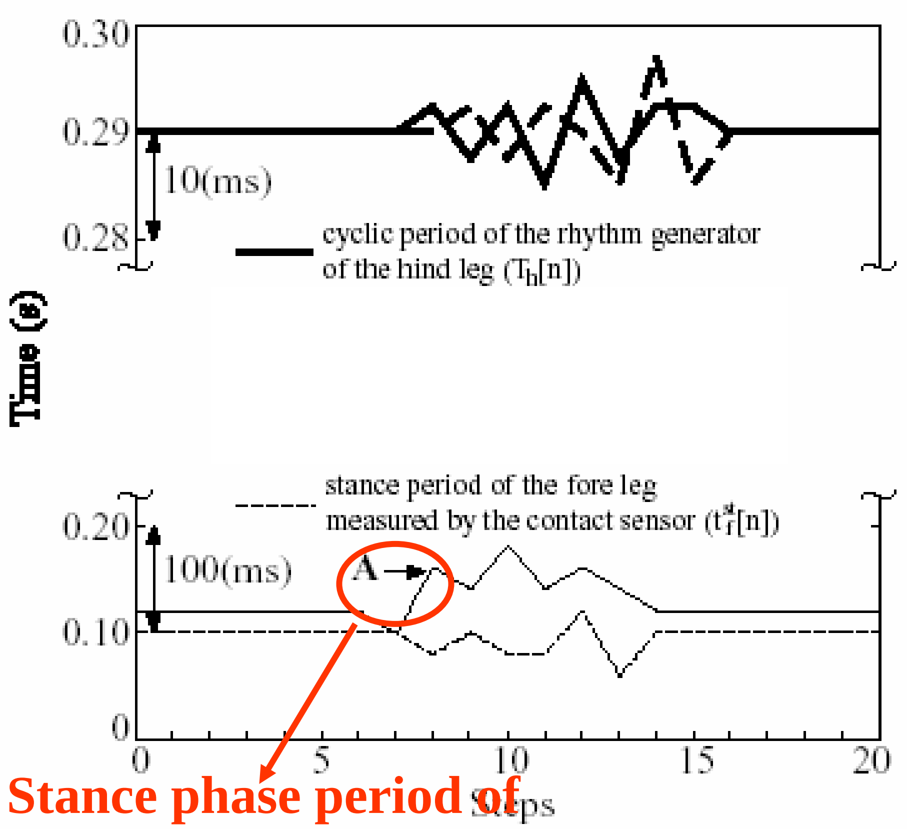
Adjustment based on DFC

- forward speed
- jump height
- energy relative to the touchdown plane

converge to the fixed point

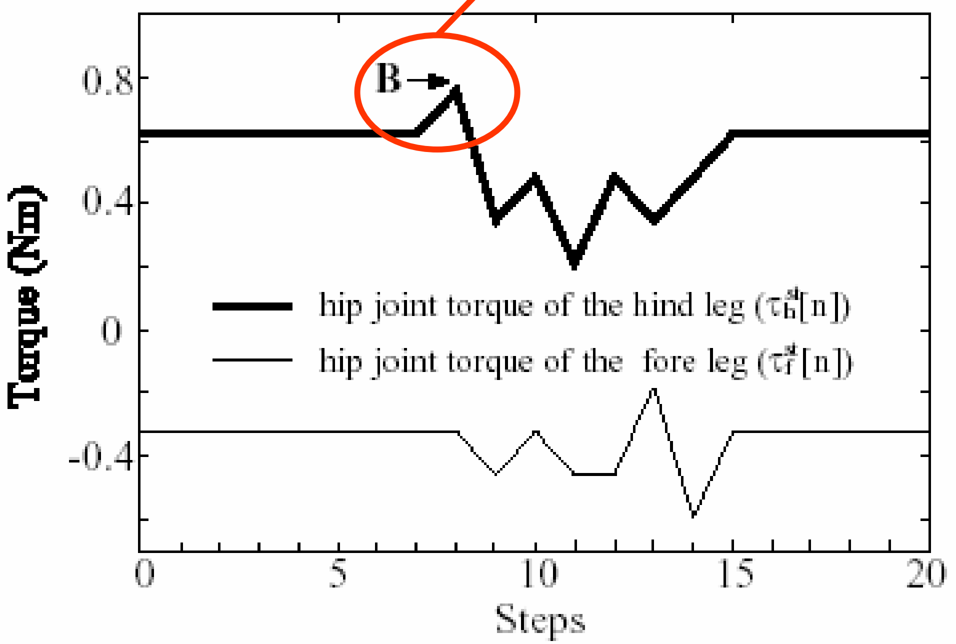
×3 slow

Anti-disturbance Capability
-Running Up a Small Step with DFC-



Stance phase period of hind legs up

Torque of hip joints of hind legs up



Converge at the steady state at the 17th step

Outlines

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- Adaptive running of a quadruped robot
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Legged Locomotion Control by CPG & Torque Generator

- The rhythm generator works well in walking and (may be) running
  - synchronized with the physical oscillations

    ⇨ *mutual entrainment*

CPG

- CPG works well while combined with torque generator
  - change of stiffness (in walking)
  - DFC of hip joint torque (in running)

easily designed and understandable

Mechanical Design

- CPG works well while combined with
  - torque generator &
  - well-designed mechanical system
    - ◆ low friction at joints
    - ◆ compliant joints
    - ◆ small mass and inertia of legs
    - ◆ …………..

My Interest in Biology

- How sensor outputs are used for control
  - reflexes (torque adjustment at PD-controller)
  - response (CPG phase modulation)
  - ……
- Adaptive Mechanics
  - change of stiffness at joints
  - flexible body
  - passive or active ankle joint
  - ……..

Outlines

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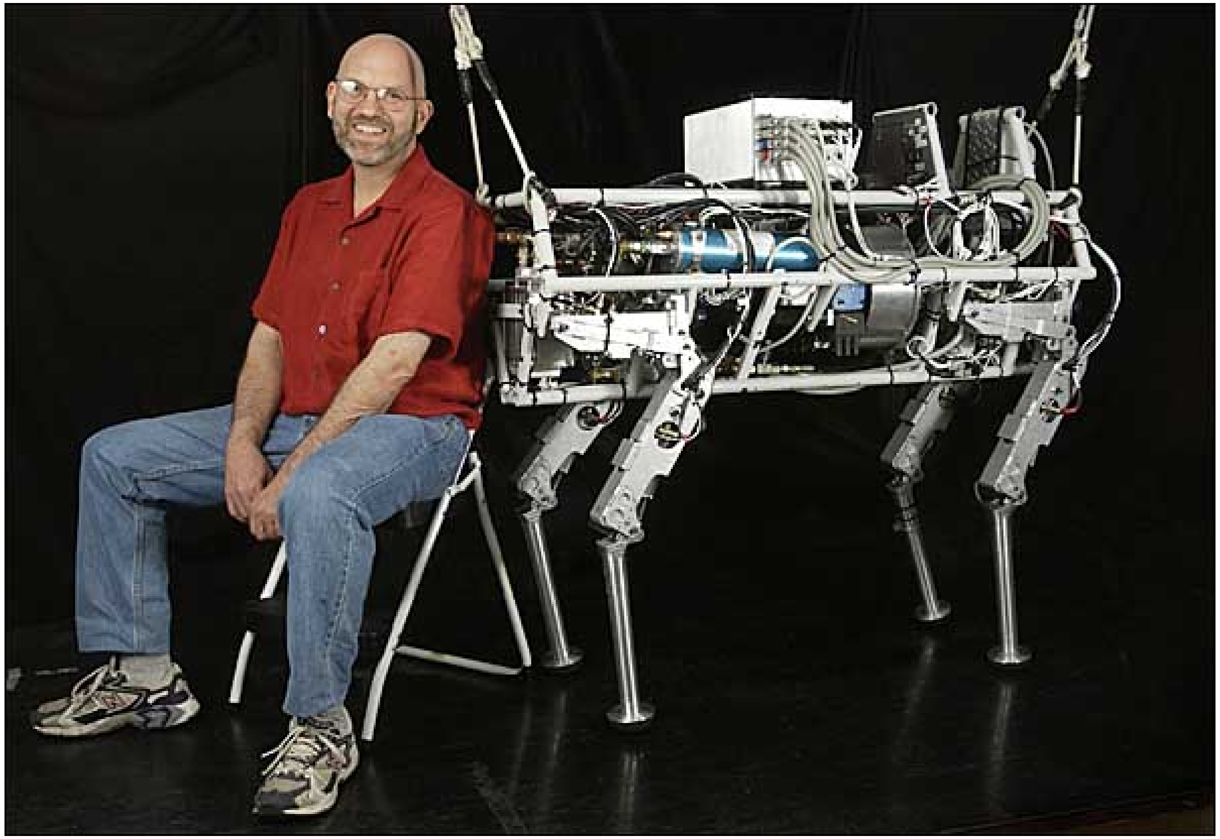
BigDog Project by Raibert

Boston Dynamics co. supported by ***DARPA***



Target

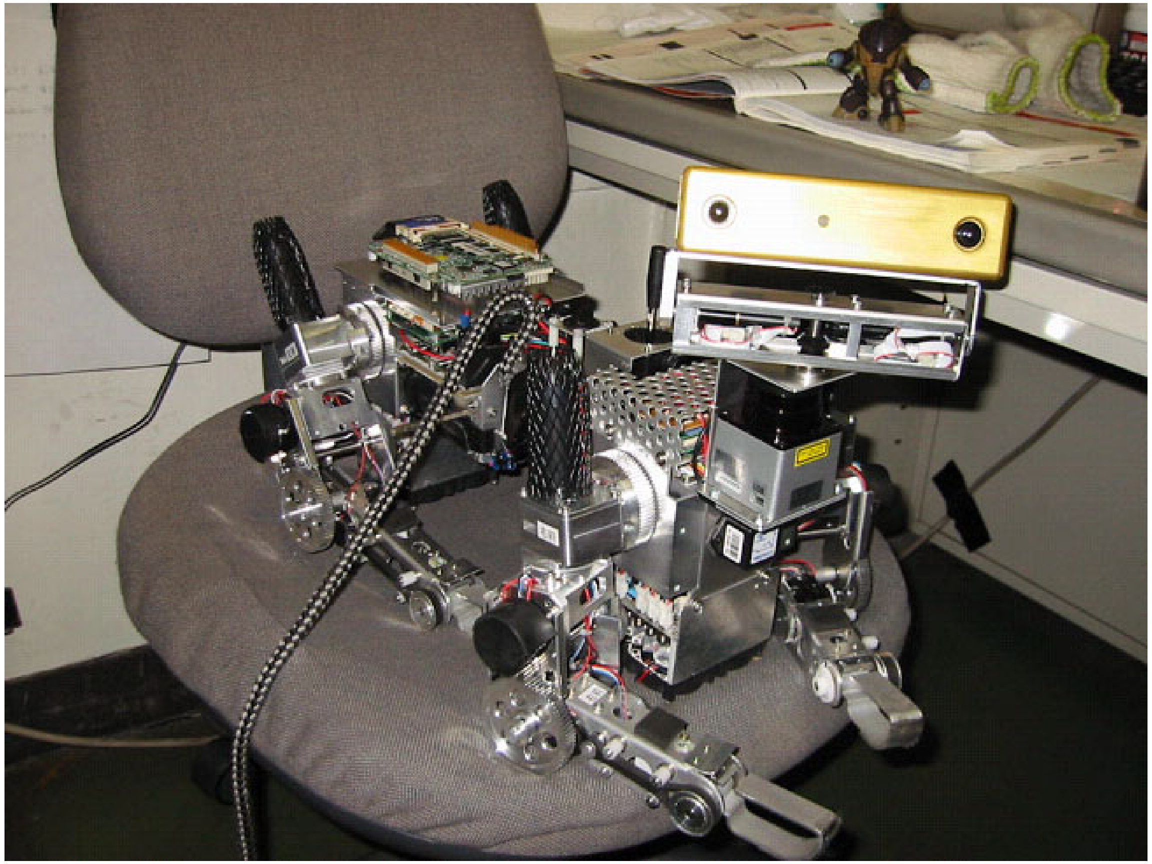
•running speed:10m/s

•climbing Mt.Fuji

Ministry of Economy, Trade and Industry (METI)

- Prototype Robot Exhib. by NEDO
  - 2005 Jun. Aichi Expo.
  - 1,500,000,000yen (US$14,000,000)
  - 65 demos (university, institute, company)
  - service robots in 2020
    - ◆ Reliability
    - ◆ Usability
    - ◆ Appearance
    - ◆ Useful Functions?
    - ◆ Costs

Tekken3



- active ankle joint
- 60W DC motor
- 9Kg only for mechanical parts

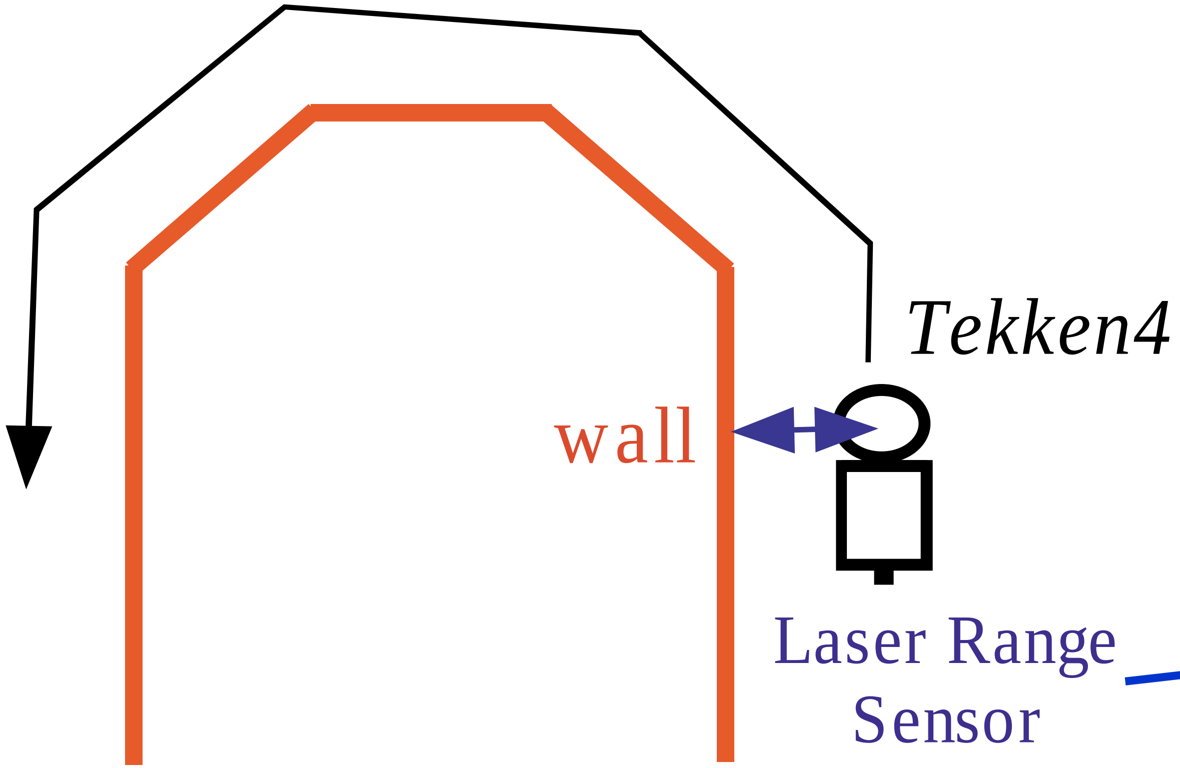
Tekken1 : 3Kg
Tekken2 : 4Kg
23W DC motor

Tekken4

- Same joints configuration with Tekken3
- Decoration of the exterior (asked by NEDO)
  - 1.5Kg
  - CFRP (Carbon Fiber Re-enforced Plastic)
  - US$18,000
- Vision Sensor
- Total: 10Kg

Aichi Expo. Prototype Robot Exhib.
Jun.9-19, 2005

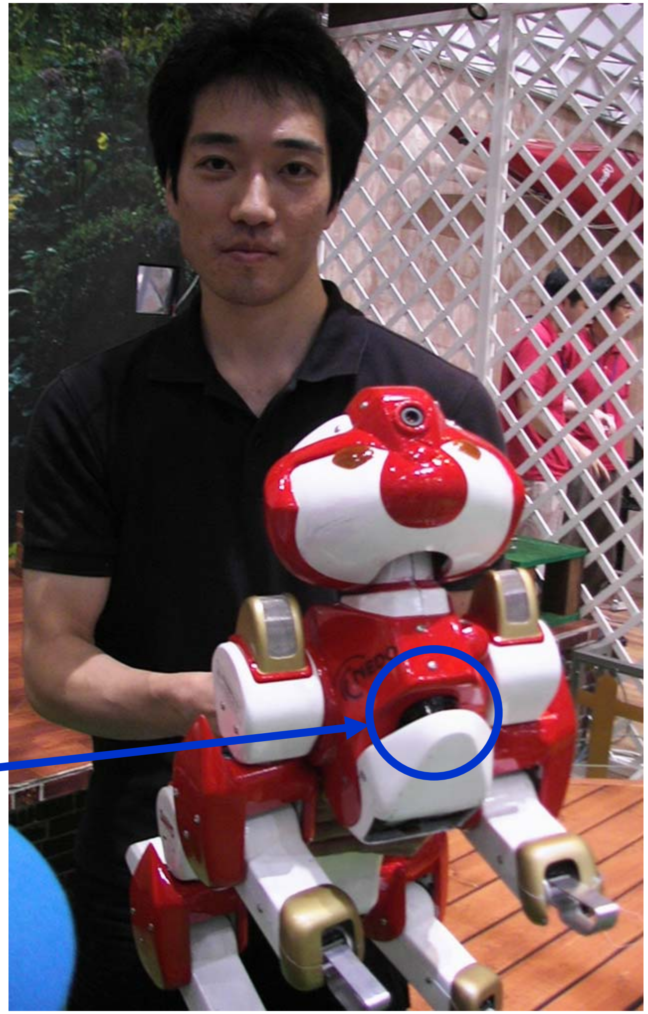
Navigation Using Laser Range Sensor



distance to the wall

⇩

control the walking direction



Tekken4 &
Dr. Fukuoka

Ministry of Education and Science

"Mobiligence" Research Group in Japan

- Biology
  - Physiology
    - Takakusaki
  - Neuroethology
    - Kanzaki
    - Aonuma
  - Computational Neurosci.
    - Yano

- System Science
    - Tsuchiya
    - Ito
- Robotics
  - Legged locomotion
  - Multi robots

emergence of pattern

grant from JSPS

(like NFS)

3rd AMAM

Int. Conf. on Adaptive Motion in Animals and Machines

Sep.25-30, 2005 in Ilmenau, Germany

Biology,
Physiology,
Biomechanics,
Robotics,
…….

http://wcms1.rz.tu-ilmenau.de/fakmb/index.php

Legged Locomotion Study is Nice!

Biology

- physiology
- neuroethology
- biomechanics
- ……..

Theory of non-equilibrium open system

- emergence of pattern
- design of adaptive system
- ……

Commercial Products

- entertainment
- house caring dog robot?
- making money?

END