Evolutionary Gait-Optimization Using a Fitness Function Based on Proprioception

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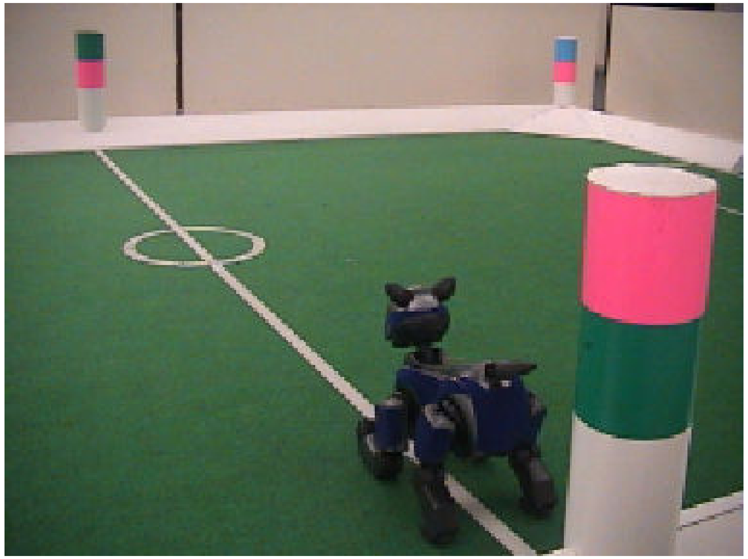
Introduction

- Motivation
  - Fast motion is important in RoboCup
  - Good gait parameter sets are hard to find manually
  - Therefore, robots should learn them automatically
- Demands
  - Easy to setup (maybe at RoboCup venue)
    - *No ceiling camera*
  - "Beacon to beacon" is limited
  - Typical localization methods cannot be used
    - *forward odometry not reliable under learning conditions*
    - *re-localization required → slow*
- Proprioception
  - Real odometry
  - Acceleration sensors

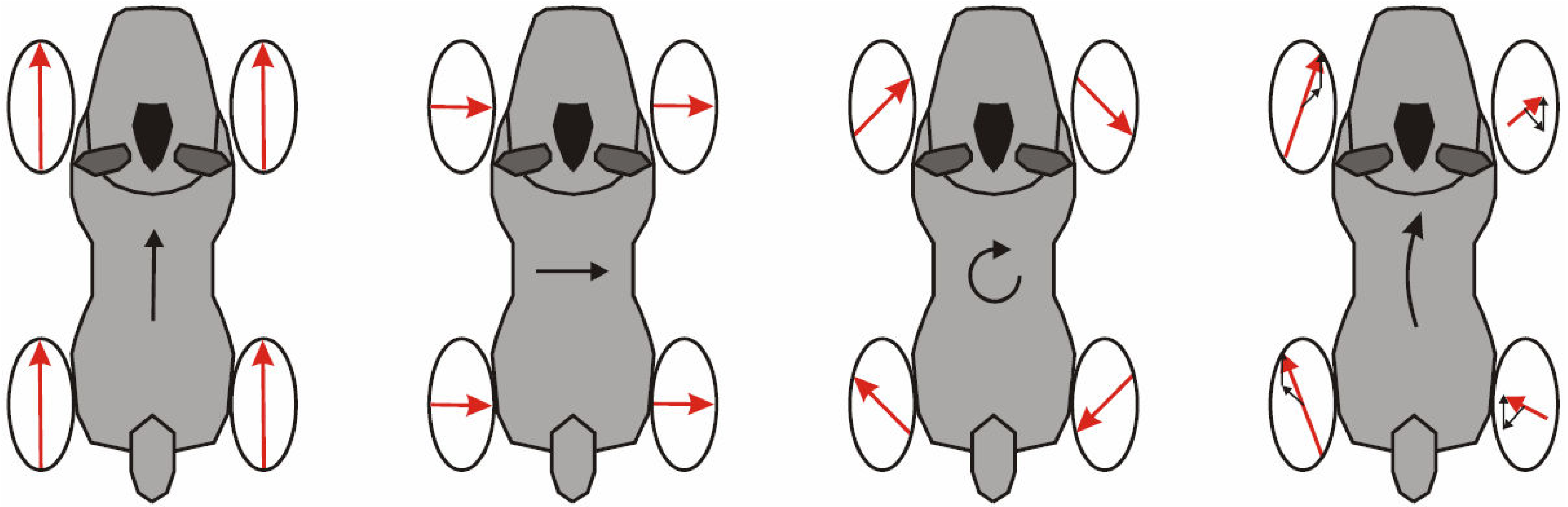


Kim and Uther, 2003

Related Work

- G. Hornby, M. Fujita, S. Takamura, T. Yamamoto, and O. Hanagata. Autonomous evolution of gaits with the Sony quadruped robot. In *Proceedings of the Genetic and Evolutionary Computation Conference*, volume 2, Orlando, Florida, USA, 1999.
- G. Hornby, S. Takamura J. Yokono, O. Hanagata, T. Yamamoto, and M. Fujita. Evolving robust gaits with Aibo. In *IEEE International Conference on Robotics and Automation 2000 (ICRA-2000)*, 2000.
- M. S. Kim and W. Uther. Automatic gait optimisation for quadruped robots. In *Proceedings of the 2003 Australasian Conference on Robotics and Automation*, Brisbane, Australia, 2003.
- N. Kohl and P. Stone. Policy gradient reinforcement learning for fast quadrupedal locomotion. In *Proceedings of the IEEE International Conference on Robotics and Automation*, May 2004.
- M. J. Quinland, S. K. Chalup, and R. H. Middleton. Techniques for improving Vision and locomotion on the Sony Aibo robot. In *Proceedings of the 2003 Australasian Conference on Robotics and Automation*, Brisbane, Australia, 2003.

Omni-Directional Walking



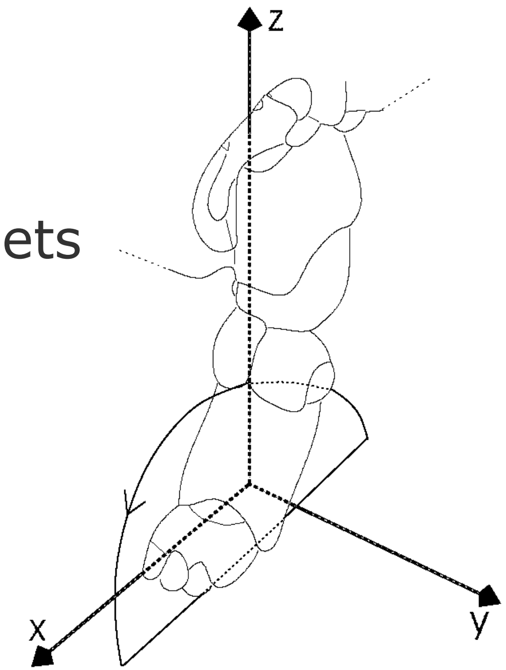
Forward　Sideward　Turning　Omni-directional

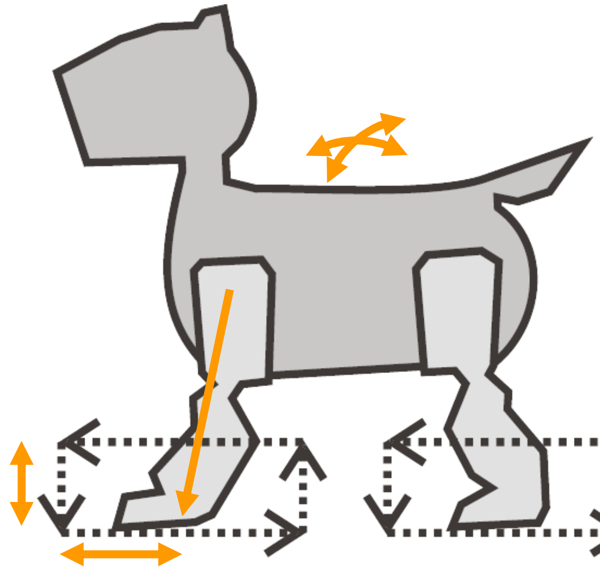
$$x^{left} = -x^r + r\theta^r \qquad x^{right} = -x^r - r\theta^r$$

$$y^{left} = -y^r + r\theta^r \qquad y^{right} = -y^r + r\theta^r$$

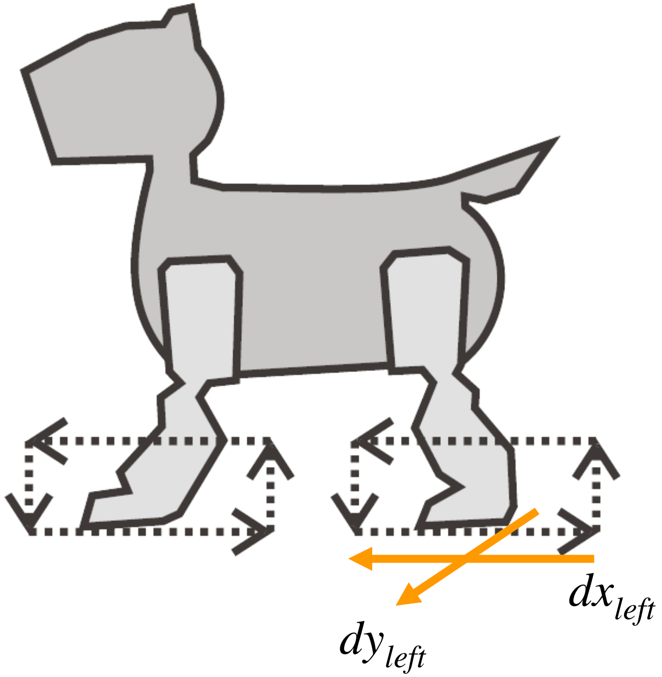
Gait Parameters

- Front/Rear locus
  - x, y, z offsets
  - step height
  - tilt
  - ground, lift, air, and lowering phases
- Step
  - size
  - duration
- Rear to Front offsets
  - x speed ratio
  - phase shift
- Body shift
  - x and y ratios
  - phase offset





Odometry

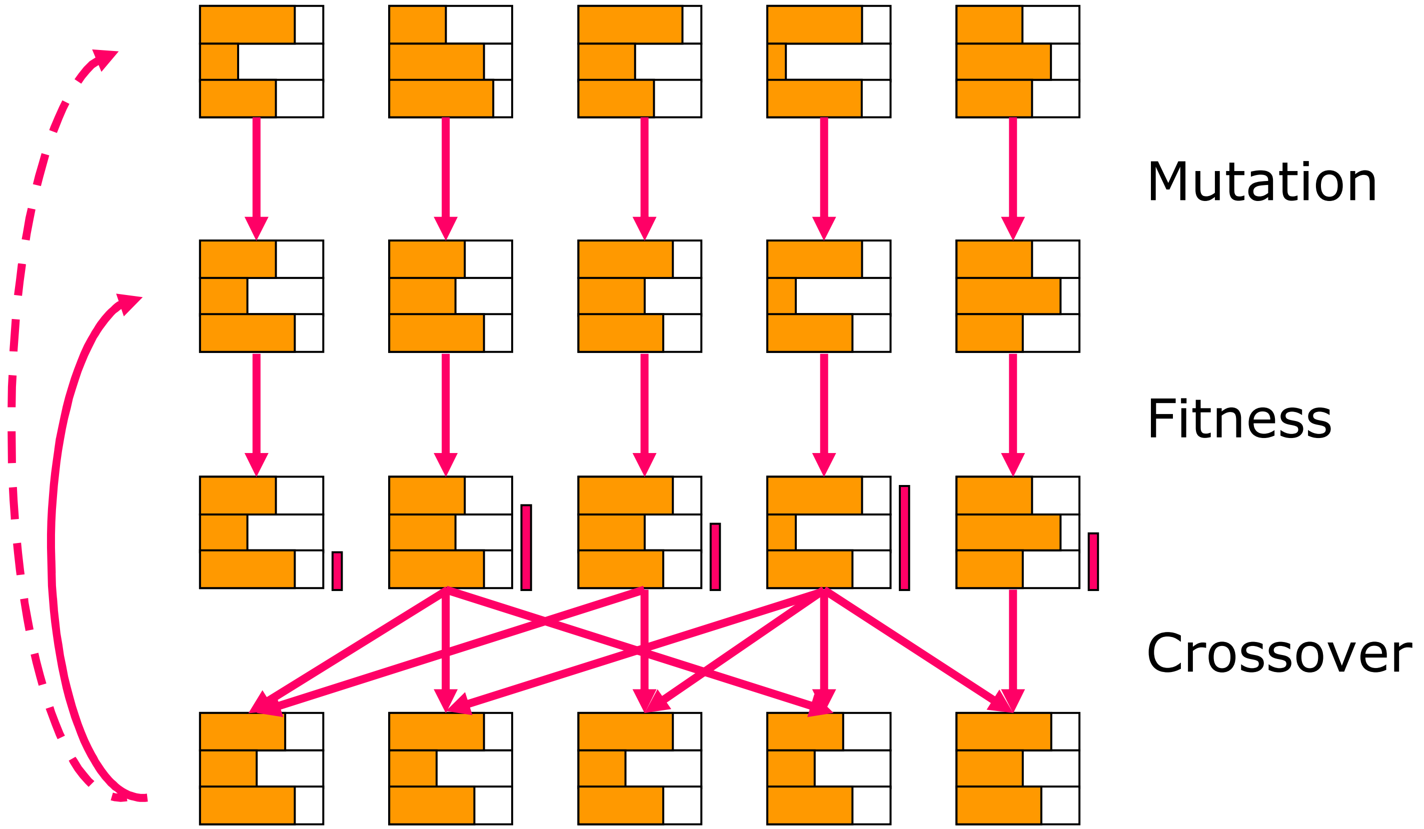


$$x^m_{t_a,t_b} = -\frac{dx^{right}_{t_a,t_b} + dx^{left}_{t_a,t_b}}{t_b - t_a}$$

$$y^m_{t_a,t_b} = -\frac{dy^{right}_{t_a,t_b} + dy^{left}_{t_a,t_b} + dx^{right}_{t_a,t_b} - dx^{left}_{t_a,t_b}}{t_b - t_a}$$

$$\theta^m_{t_a,t_b} = -\frac{dx^{right}_{t_a,t_b} - dx^{left}_{t_a,t_b}}{r(t_b - t_a)}$$

Evolutionary Algorithm

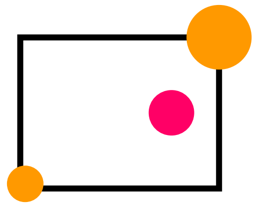


Fitness Function

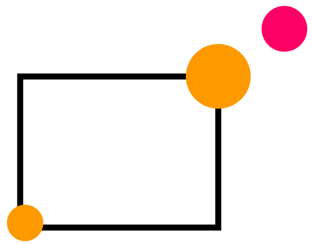
- Procedure
  - Gait parameter set of an individual is selected
  - Robot walks for 5 seconds
  - The first two seconds are ignored
- Fitness is a weighted combination of
  - the deviation between requested motion and measured motion,
  - the standard deviation of the measurements of the three acceleration sensors in the robots body
- Goal
  - Move fast and smooth

Crossover

- Selecting individuals
  - Each pair of individuals for crossover are drawn randomly based on their fitness
- Combining individuals
  - Interpolation
    - *Random interpolation between parameters weighted by the fitness of the individuals*



  - Extrapolation
    - *Extrapolating the parameters of one individual away from the other*
    - *Selection again randomly, weighted by the fitness*



Experiments

- Experiments 1 (ERS-210) and 2 (ERS-7)
  - Robot is moving from goal to goal
  - It is turned manually
  - 5 seconds per individual (first 2 seconds ignored)
  - Best individual is selected as basis for a new population after a restart
  - Experiments of about 3 hours
- Experiment 2 (ERS-7)
  - Same as experiment 1, but robot is walking backward
- Experiment 3 (ERS-7)
  - Robot is following the ball
  - Ball is moved manually
  - Took about 4 hours

Resulting Gaits – ERS-210

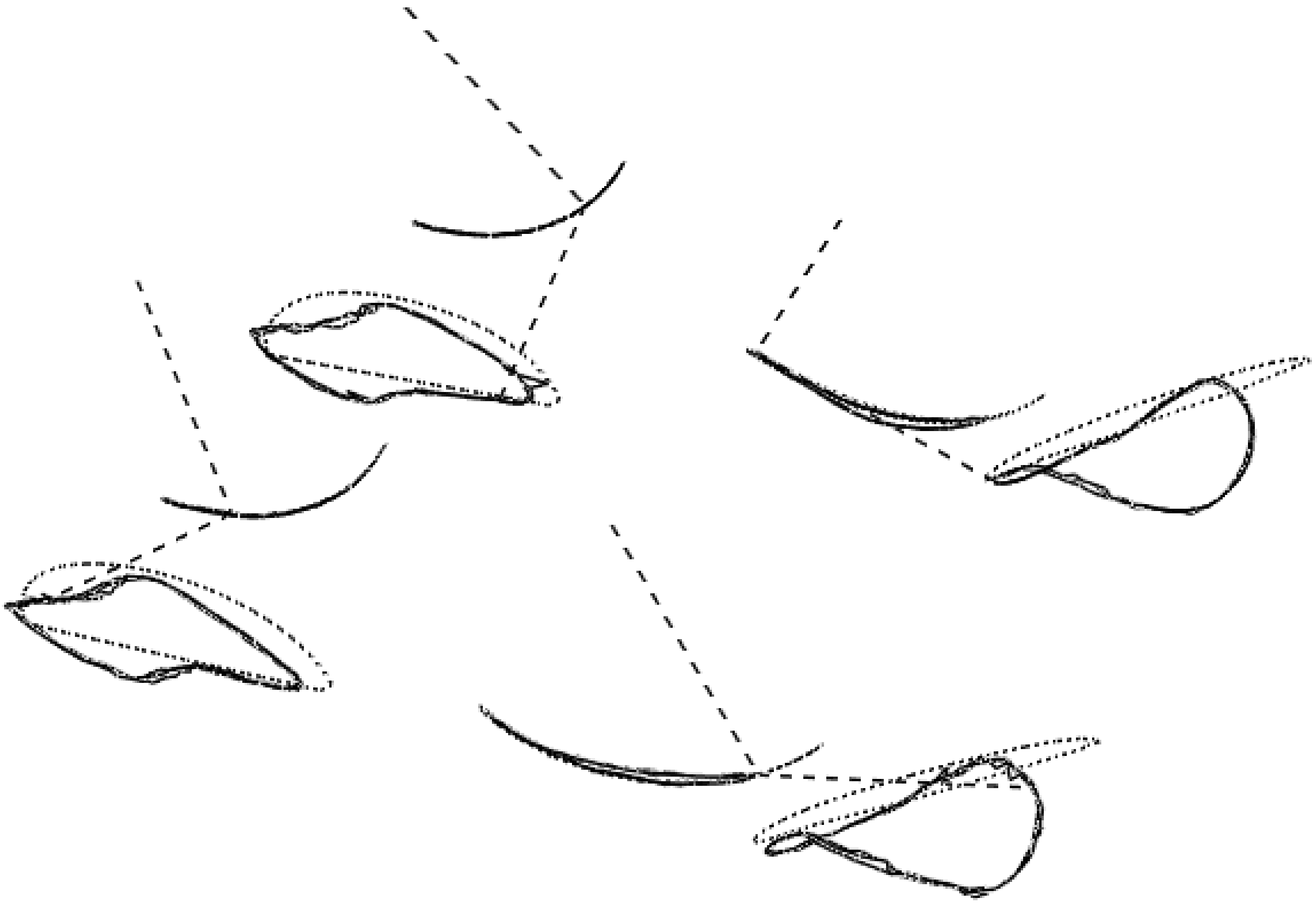
Forward: 311 mm/s

Resulting Gait Parameters

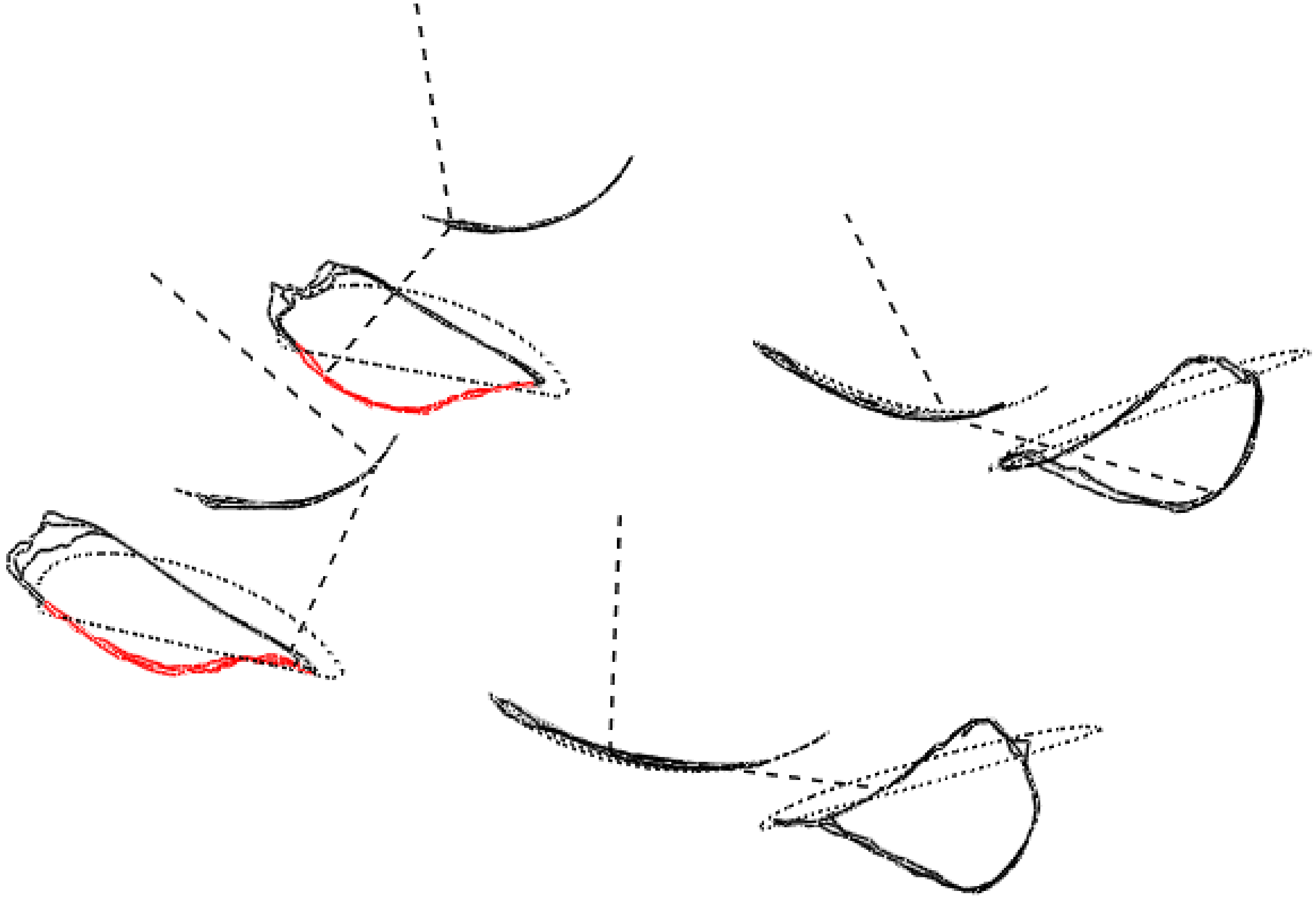
Parameter	Initial Value	Best Value
Front locus		
z offset	76.85	58.97
y offset	78.1	67.24
x offset	55.88	63.26
step height	5.0	6.14
tilt	-0.25	-0.48
ground phase	0.5	0.64
lift phase	0.06	0.04
lowering phase	0.06	0.12
Step		
size	76.0	89.77
duration	0.64	0.512
Rear to Front offsets		
x speed ratio	1.1	1.0
phase shift	0	-0.012

Parameter	Initial Value	Best Value
Rear locus		
z offset	108.72	111.54
y offset	76.95	58.09
x offset	-45.216	-35.96
step height	24.0	27.27
tilt	0.05	0.12
ground phase	0.5	0.34
lift phase	0.06	0.19
lowering phase	0.06	-0.02
Body shift		
x ratio	0	1.12
y ratio	0	-0.10
phase offset	0	0.35

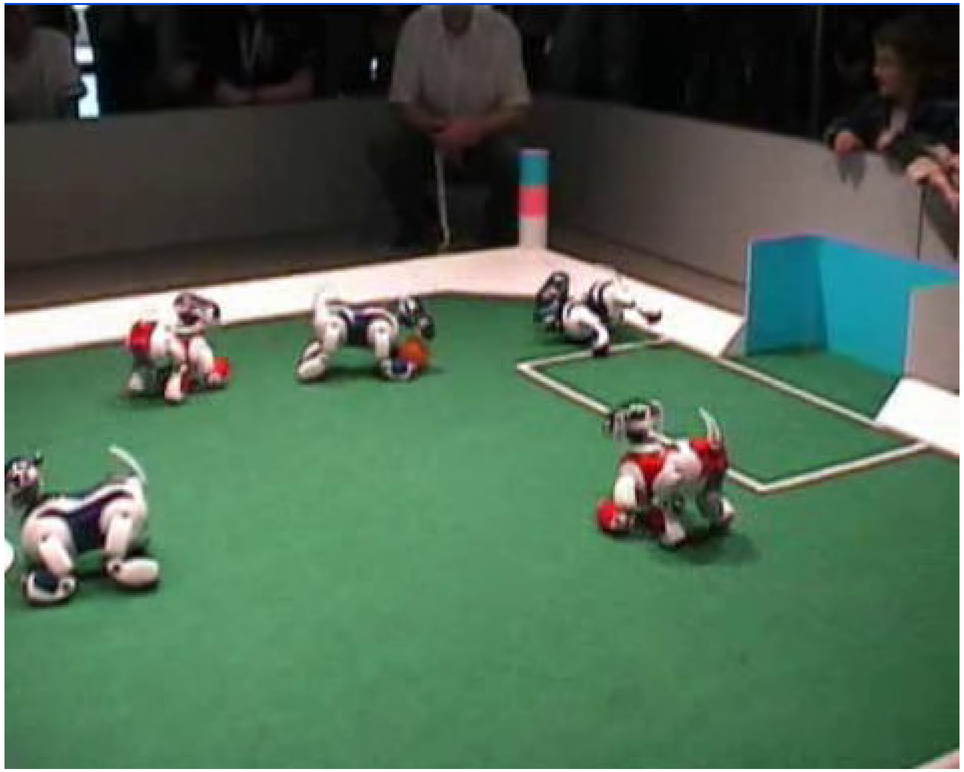
Target Joint Angles and Actual Joint Angles without Ground Contact



Target Joint Angles and Actual Joint Angles with Ground Contact



Resulting Gaits – ERS-7



Forward:	400 mm/s
Backward:	296 mm/s
Ball following:	331 mm/s, 195°/s

Conclusions and Future Work

- Conclusions
  - Gait-Optimization
  - Fitness Function based on odometry and vibrations
  - Drawing of individuals
  - Interpolation/extrapolation scheme for crossover
- Future work
  - Learning different parameter sets in parallel
  - Interpolate between these sets even during learning


SONY

Questions?