Evolution des Zweibeinigen Laufens

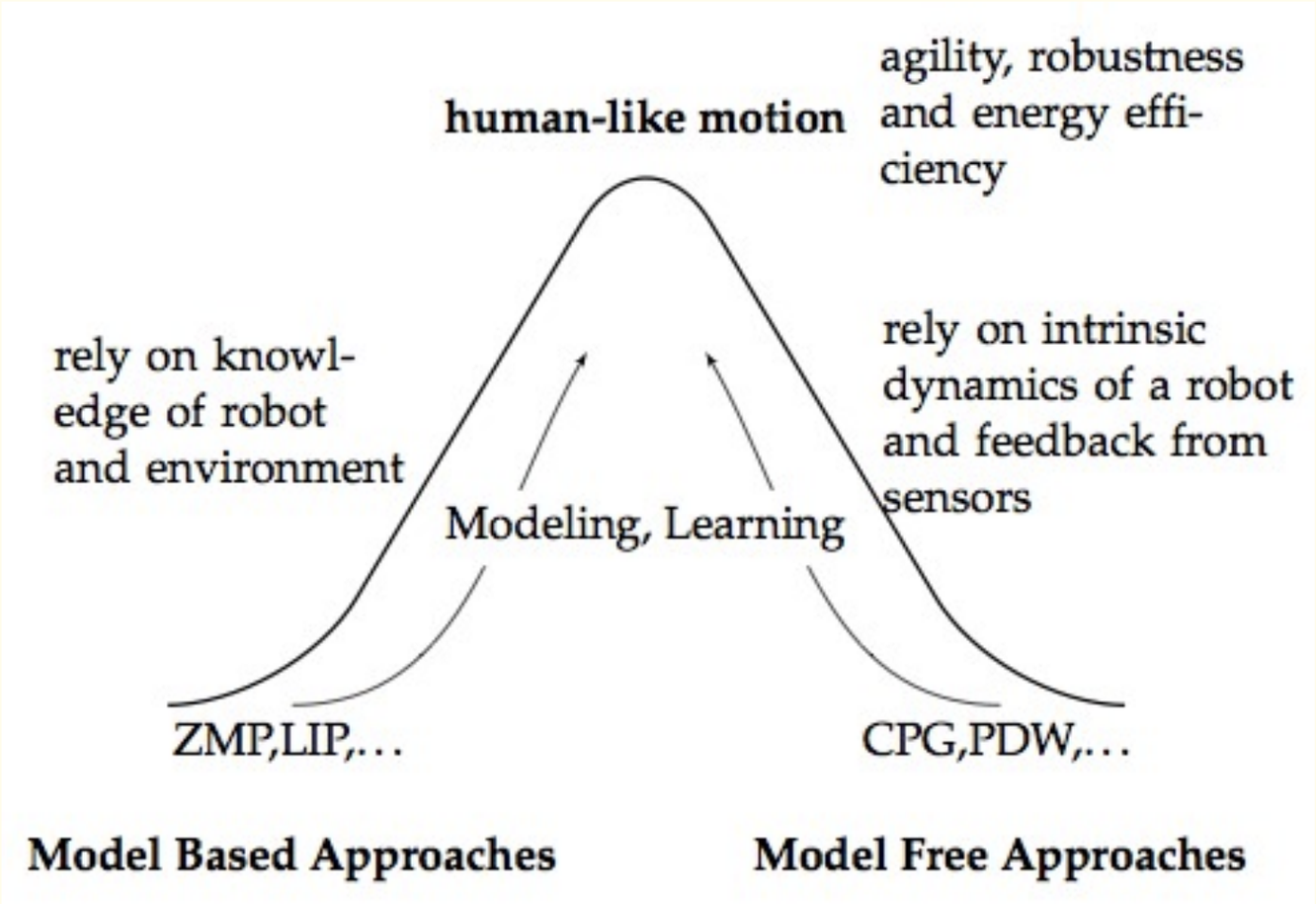
Denis Erfurt

Problembeschreibung

- generell: Roboter von A nach B befördern
- zweibeiniges Laufen ist essenzielles Fortbewegungsproblem
- größerer Grad an Beweglichkeit gegenüber anderen Methoden
- größere Robustheit
- fachübergreifendes Problem: mechanisch, biologisch, physikalisch, ...
- Interaktion mit Entscheidungen aus einer „höheren Ebene“

Approaches

- keyframes
- zero moment point
- cyclic function
- neural oscillator
- limit cycle walking

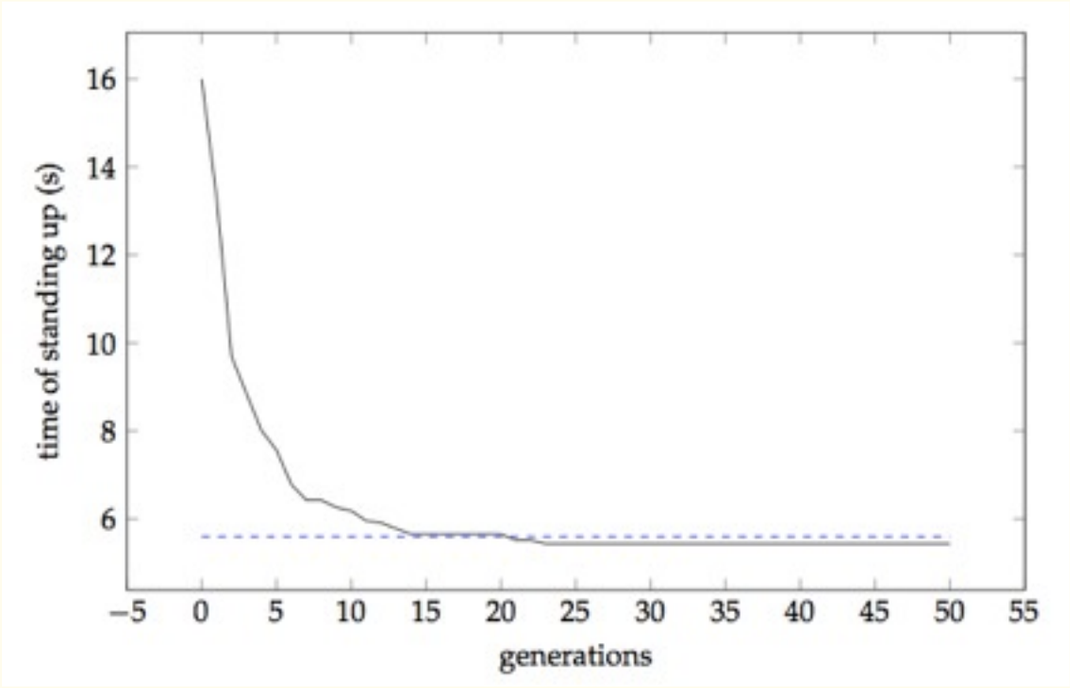


Keyframe

+ simpel, schnell
- Interpoliert, keine Sensor kopplung

Keyframe

- Keyframe Motion Optimization
- Keyframe Motion Auto-generation

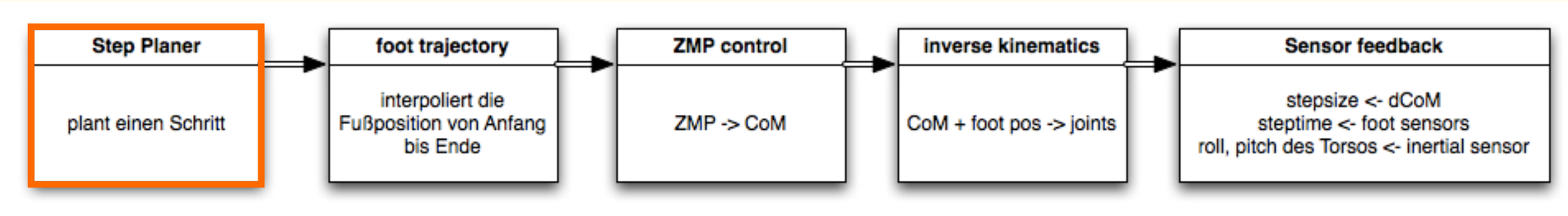


höhe des CoM = Fitness

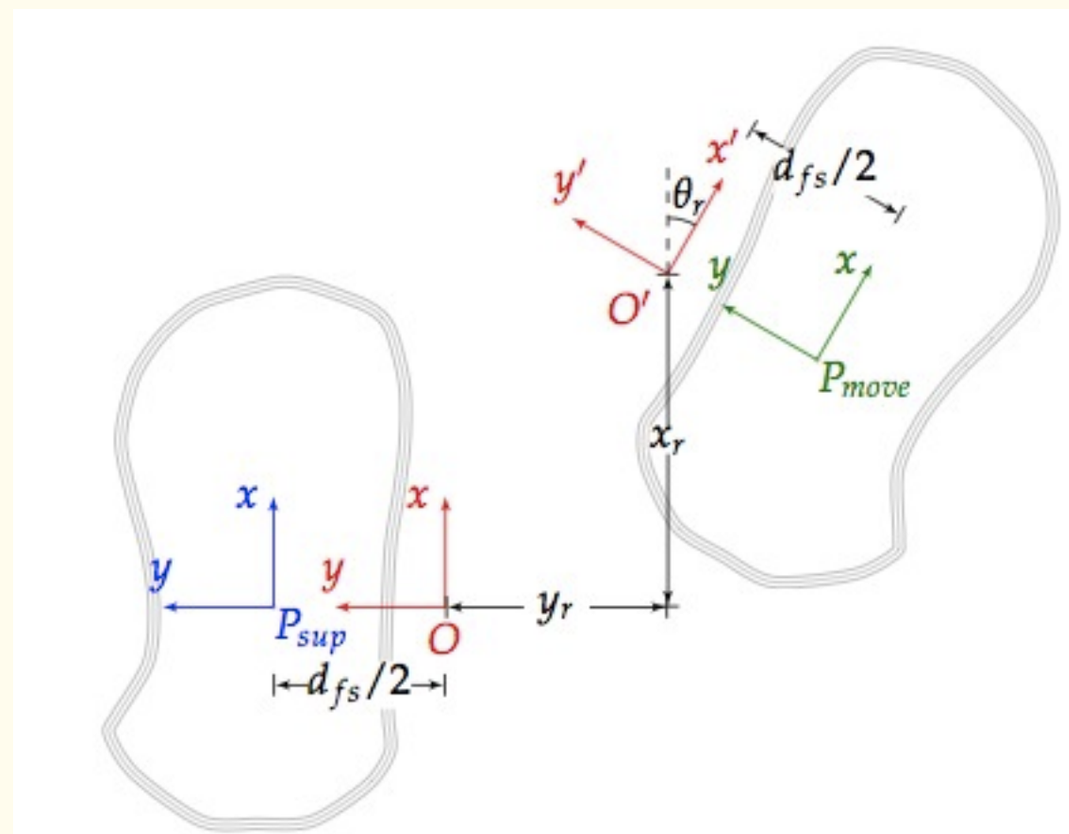
ZMP kontrolle mit LIP

- Support Polygon
- CoM: Center of Mass
- ZMP: Zero Moment Point

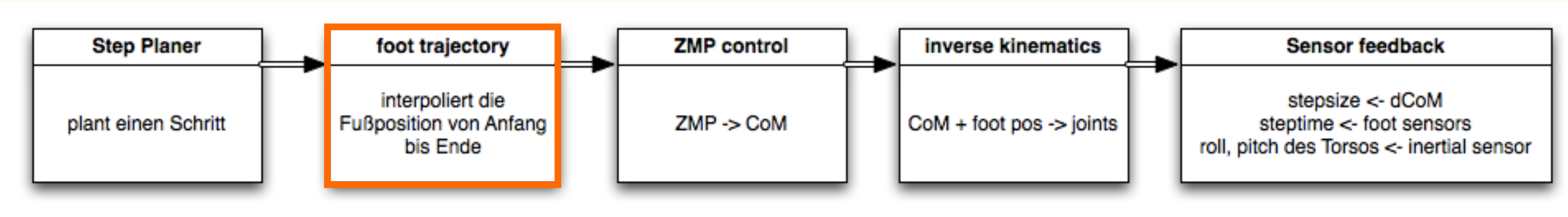
ZMP kontrolle mit LIP



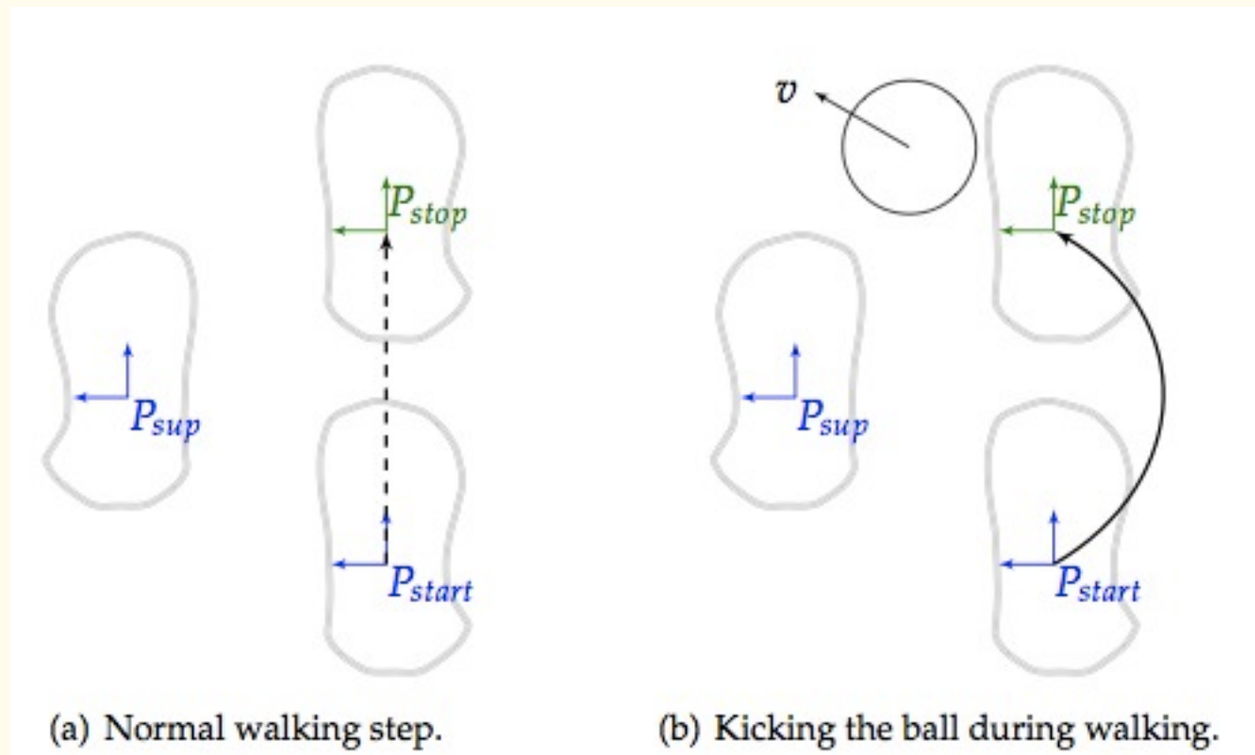
- bekommt eine Anfrage
- plant genau einen Schritt



ZMP kontrolle mit LIP

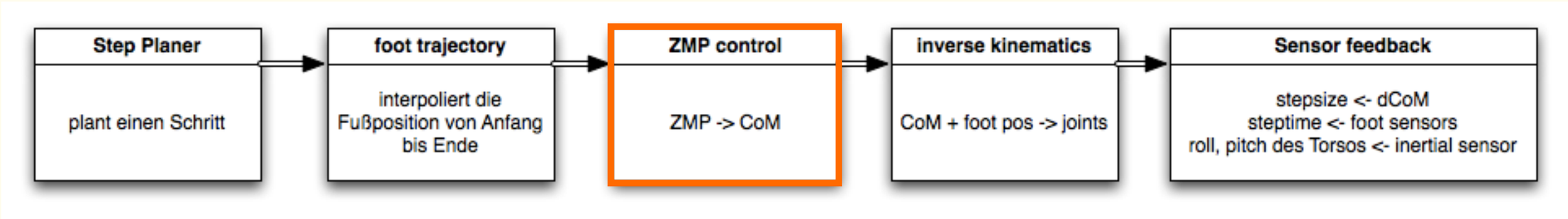


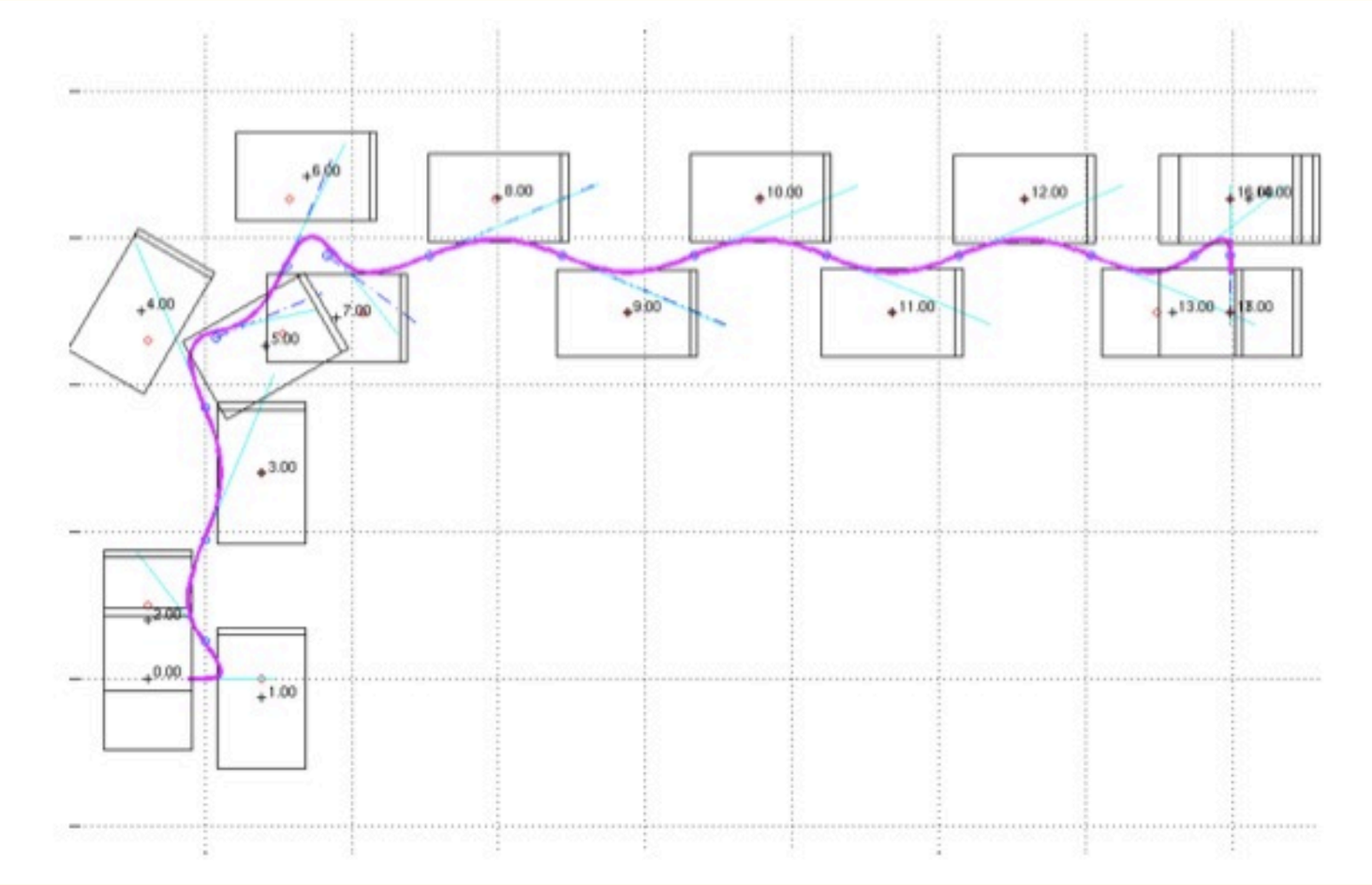
$$\alpha(t) = 1/(1 + \lambda e^{-(t-0.5)})$$
$$s(t) = (1 - \alpha(t))S_0 + \alpha(t)S_1$$
$$\beta(t) = \cos((t - 0.5)\pi)$$
$$h(t) = \beta(t)H$$



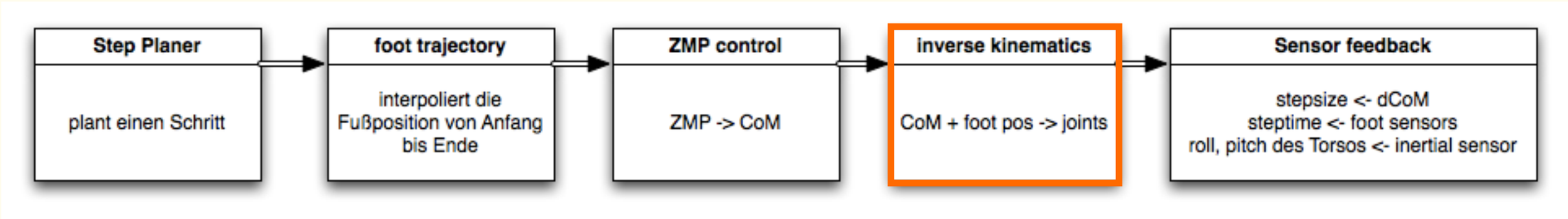
(a) Normal walking step. (b) Kicking the ball during walking.

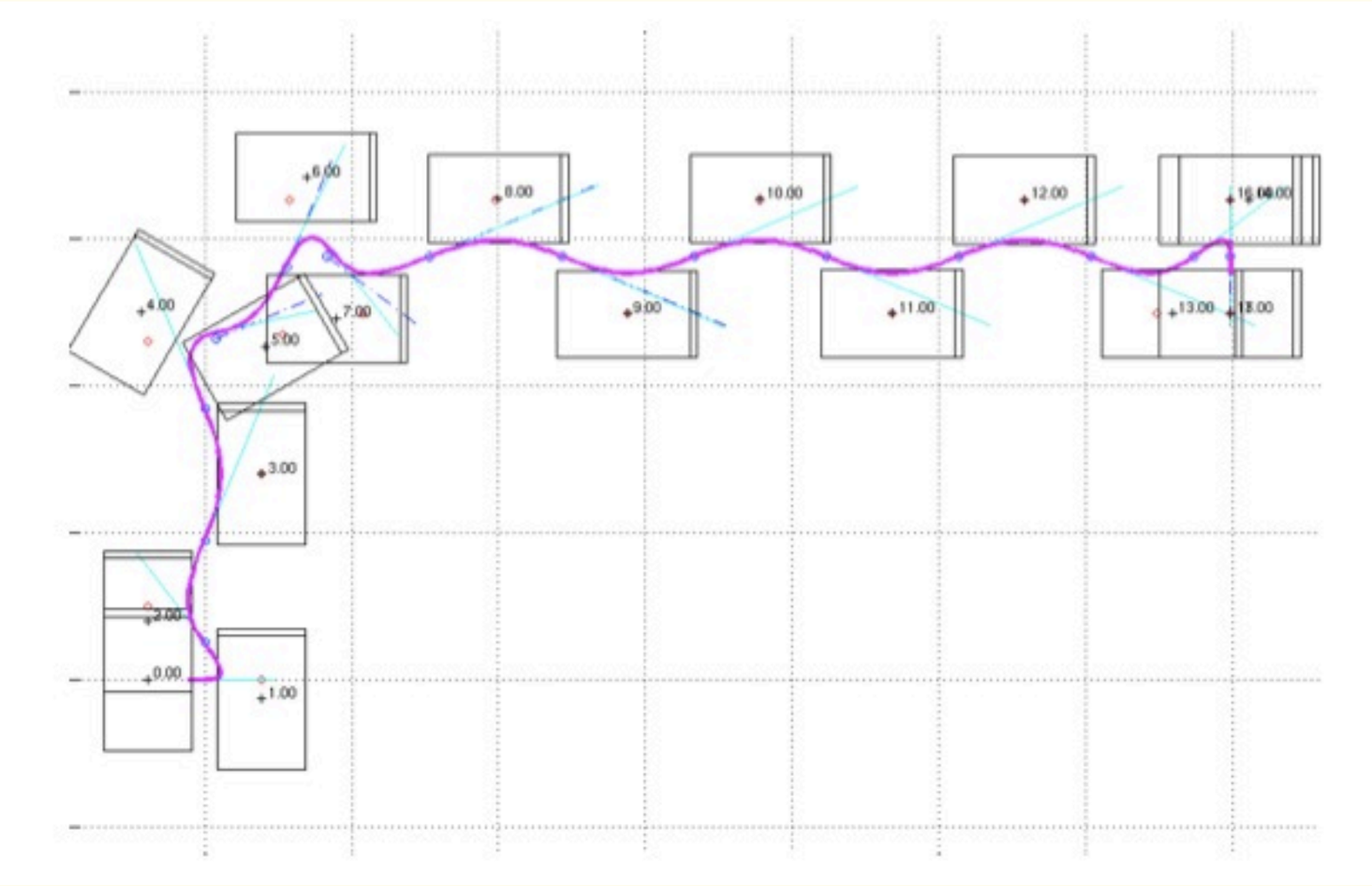
ZMP kontrolle mit LIP



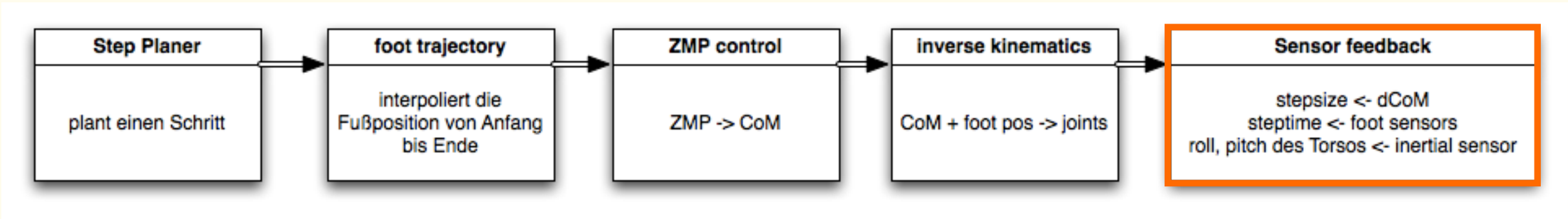


ZMP kontrolle mit LIP



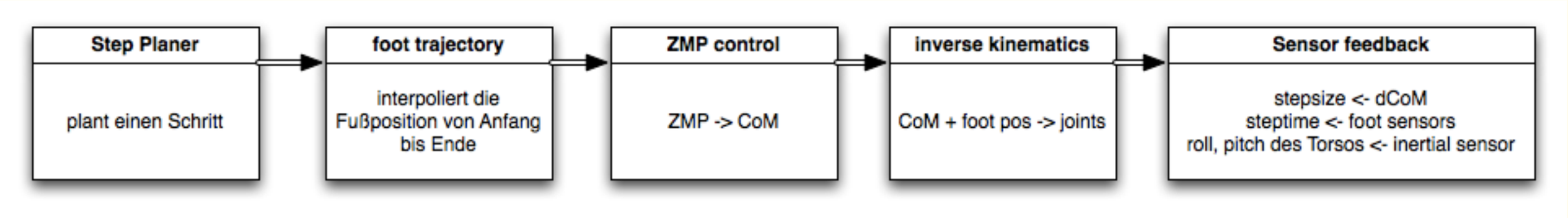


ZMP kontrolle mit LIP

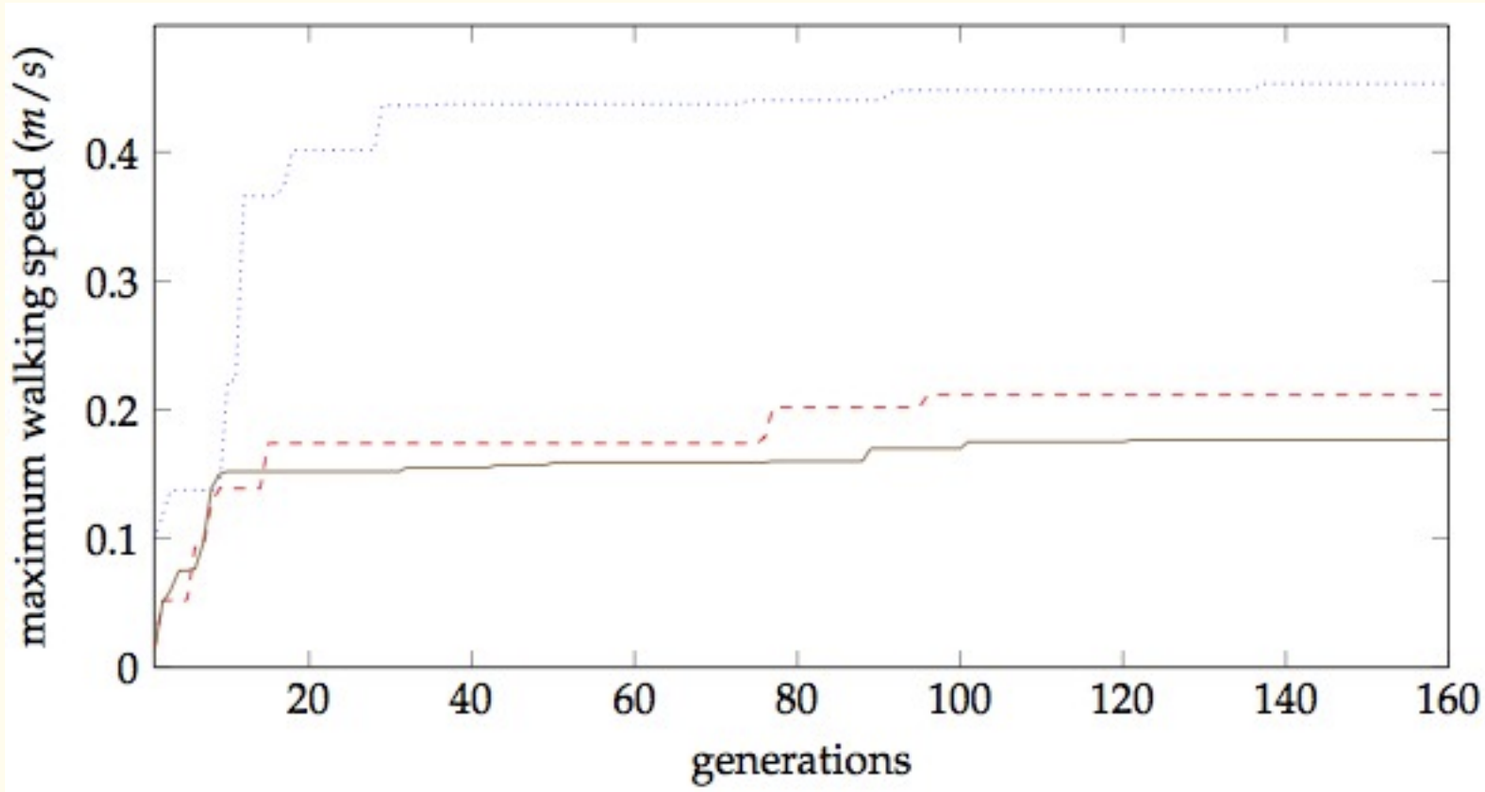


- Fehlerbeseitigung mittels PID Controller
  - Schrittweite ~ -Differenz der CoMs
  - Schrittdauer ~ Fußsensoren
  - roll und pitch des Torsos ~ Trägheitssensor

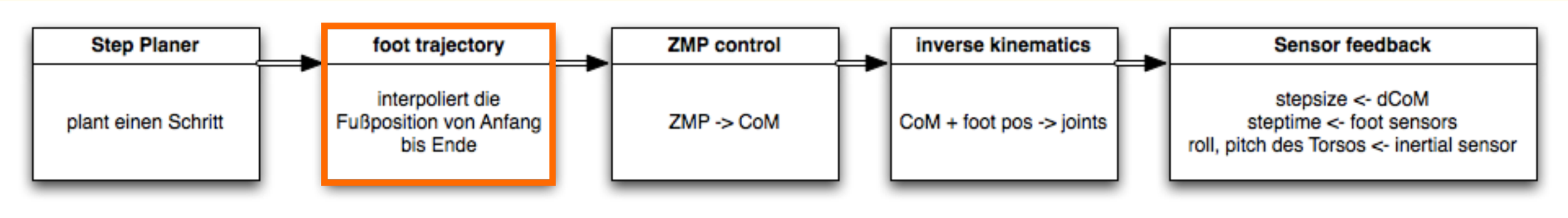
ZMP kontrolle mit LIP

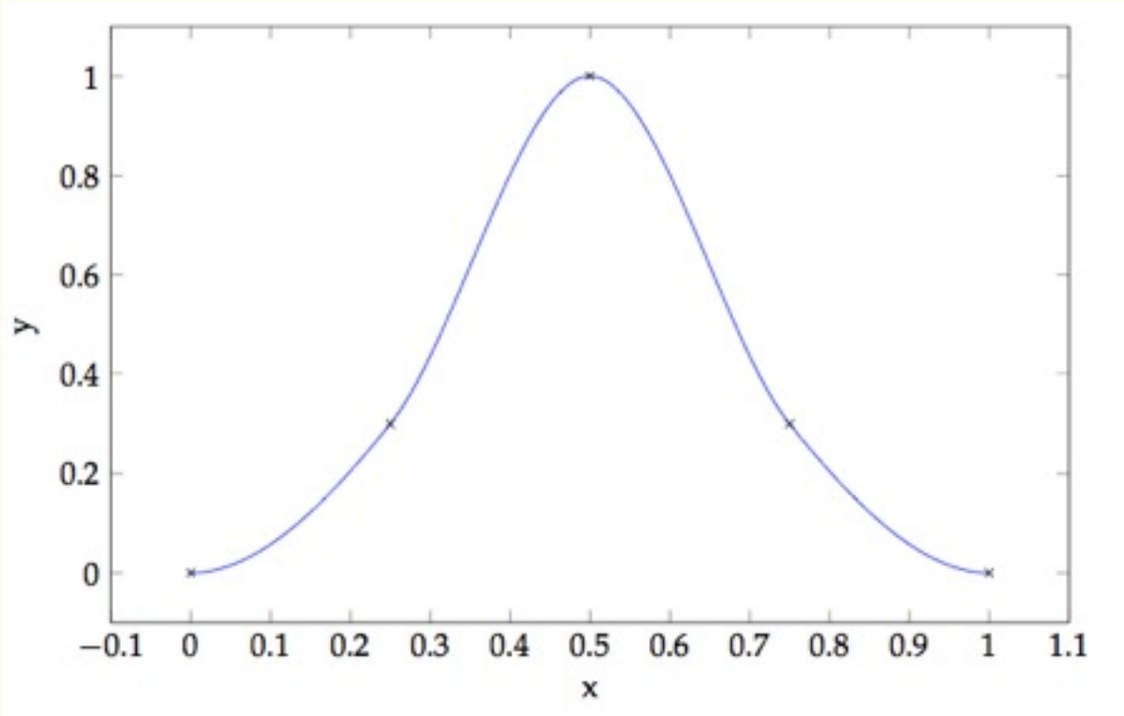


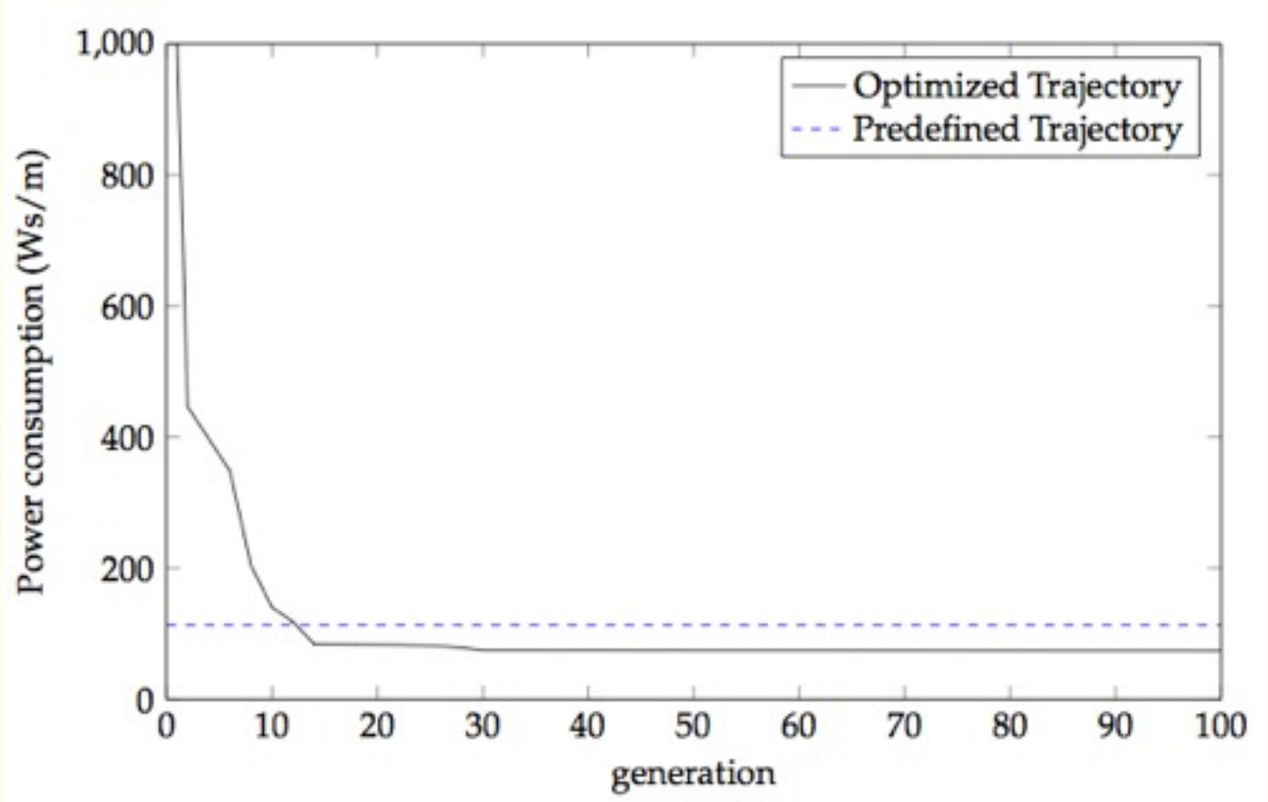
- Optimierung der 19 Parameter durch EA:
  - 100 Genotypen
  - Überlebensrate, Crossoverrate, Mutationsrate: 1/3
  - 10 % Elite



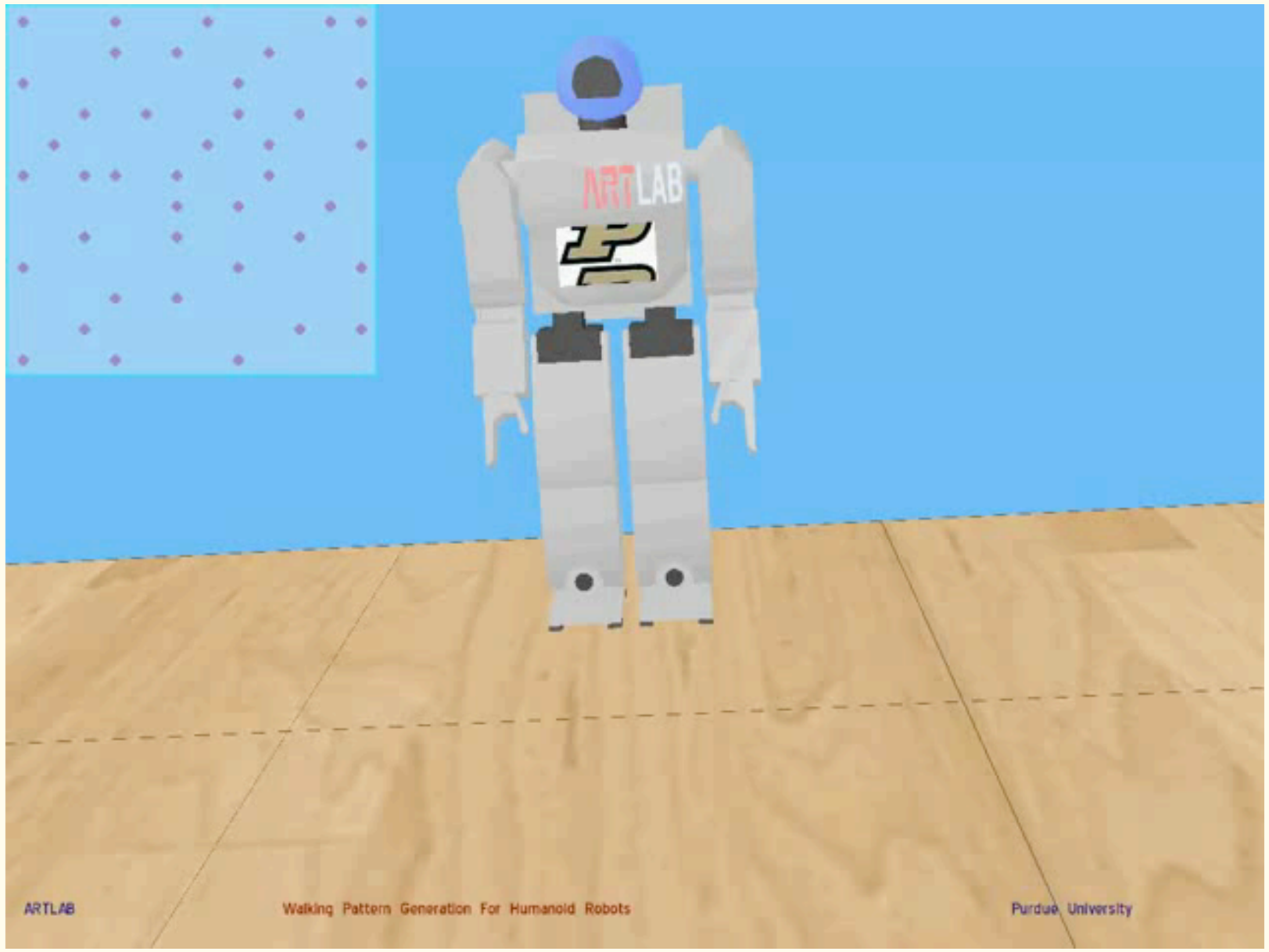
ZMP kontrolle mit LIP





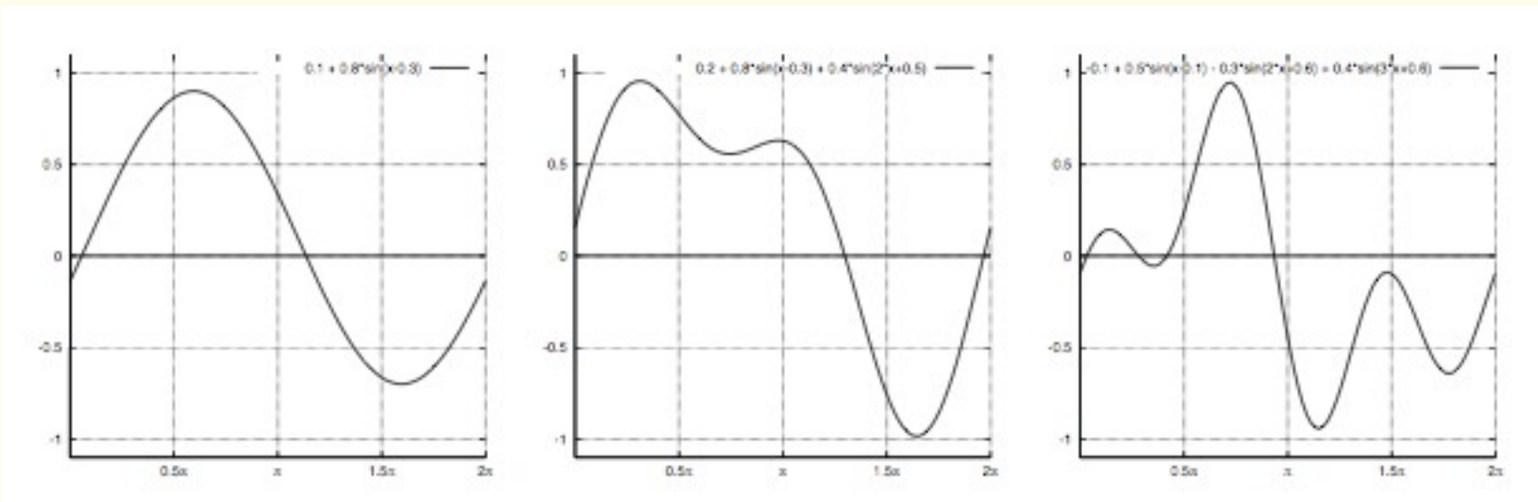


CPG


ARTLAB
ARTLAB
Walking Pattern Generation For Humanoid Robots
Purdue University

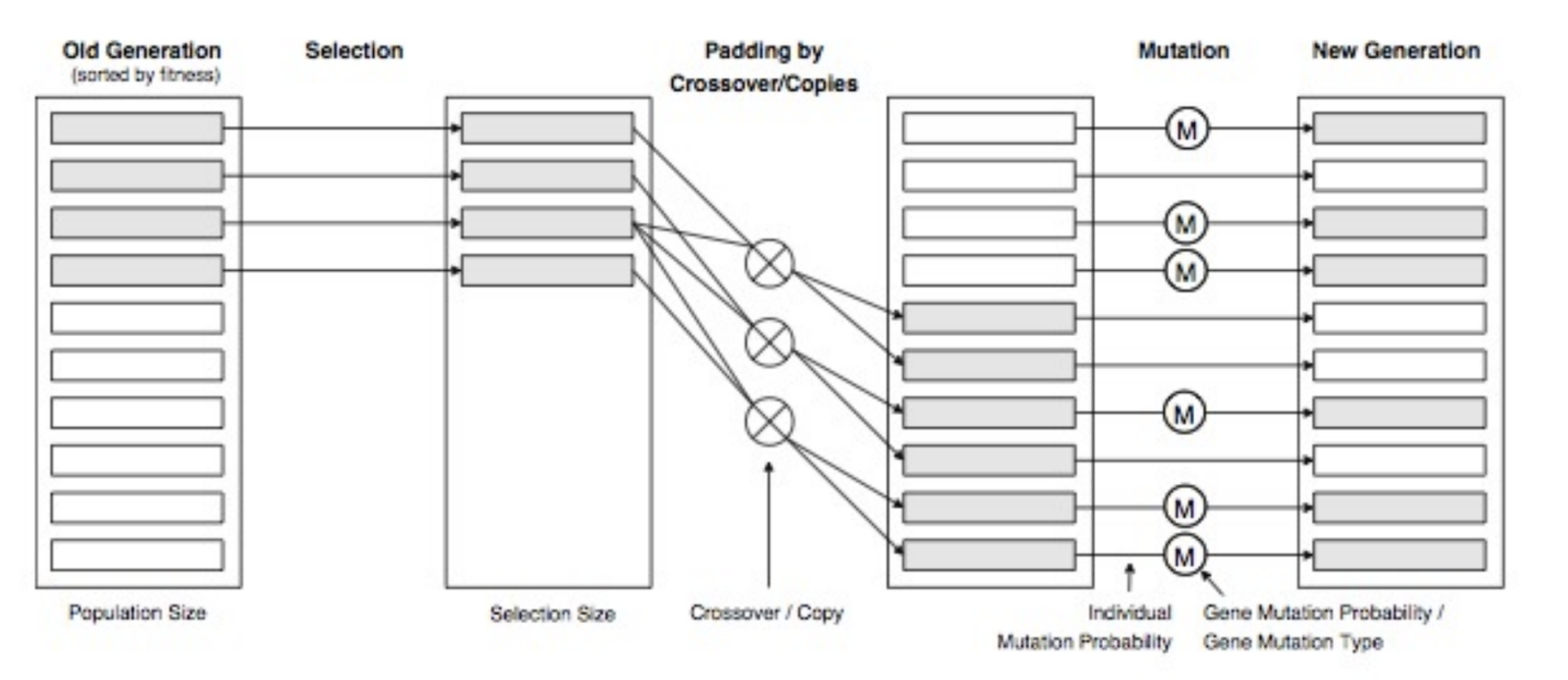
Cyclic Function

- Fourier Serie



- 1+2N Parameter
- 19 Joints = 19+38N
- Symmetrie => 10+20N

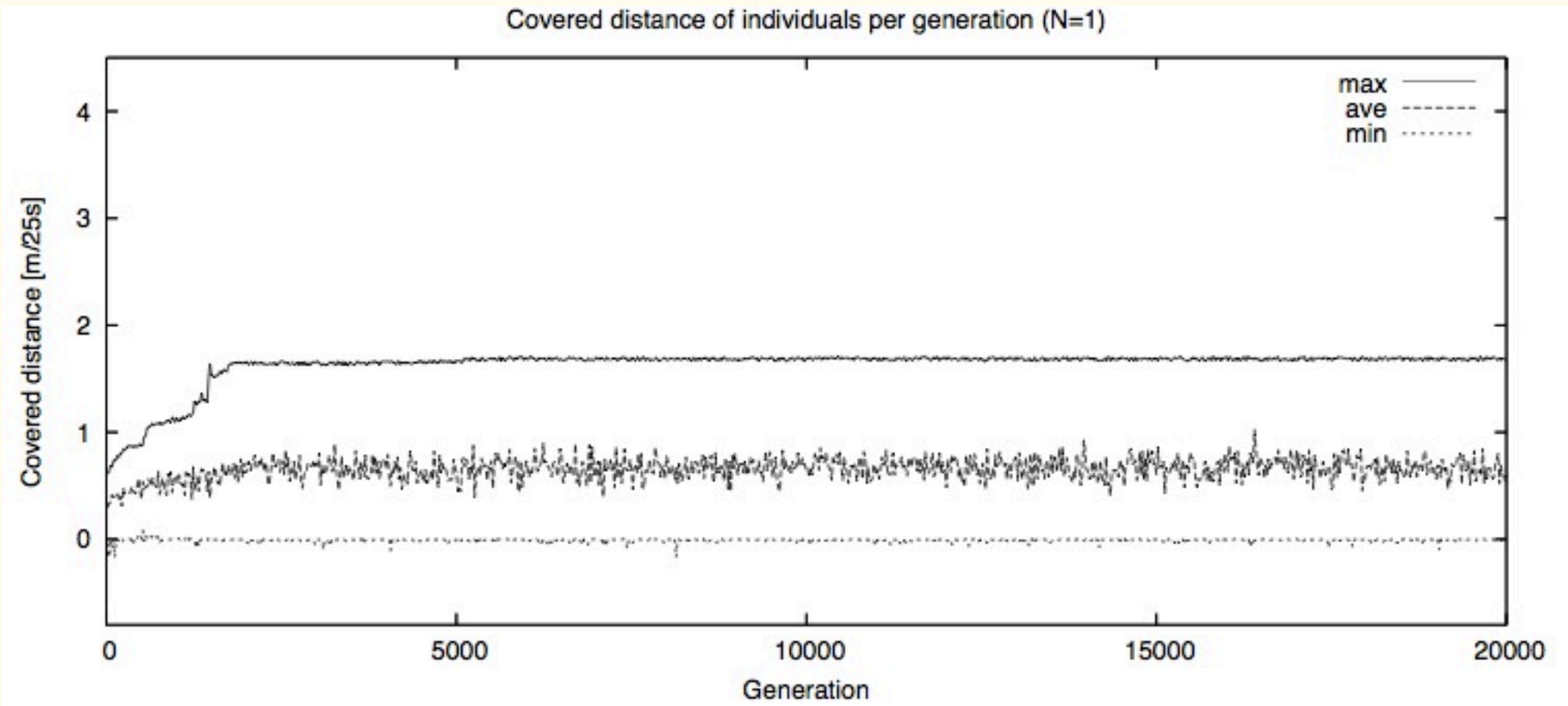
Cyclic Function



Parameter	Value
Episode Duration	$25s$
Population Size	50
Selection Size	15
Padding Type	Crossover
Mutation Probability for an Individual	0.5
Mutation Probability for a Gene	0.2
Gaussian Variance when Mutating a Gene	0.05

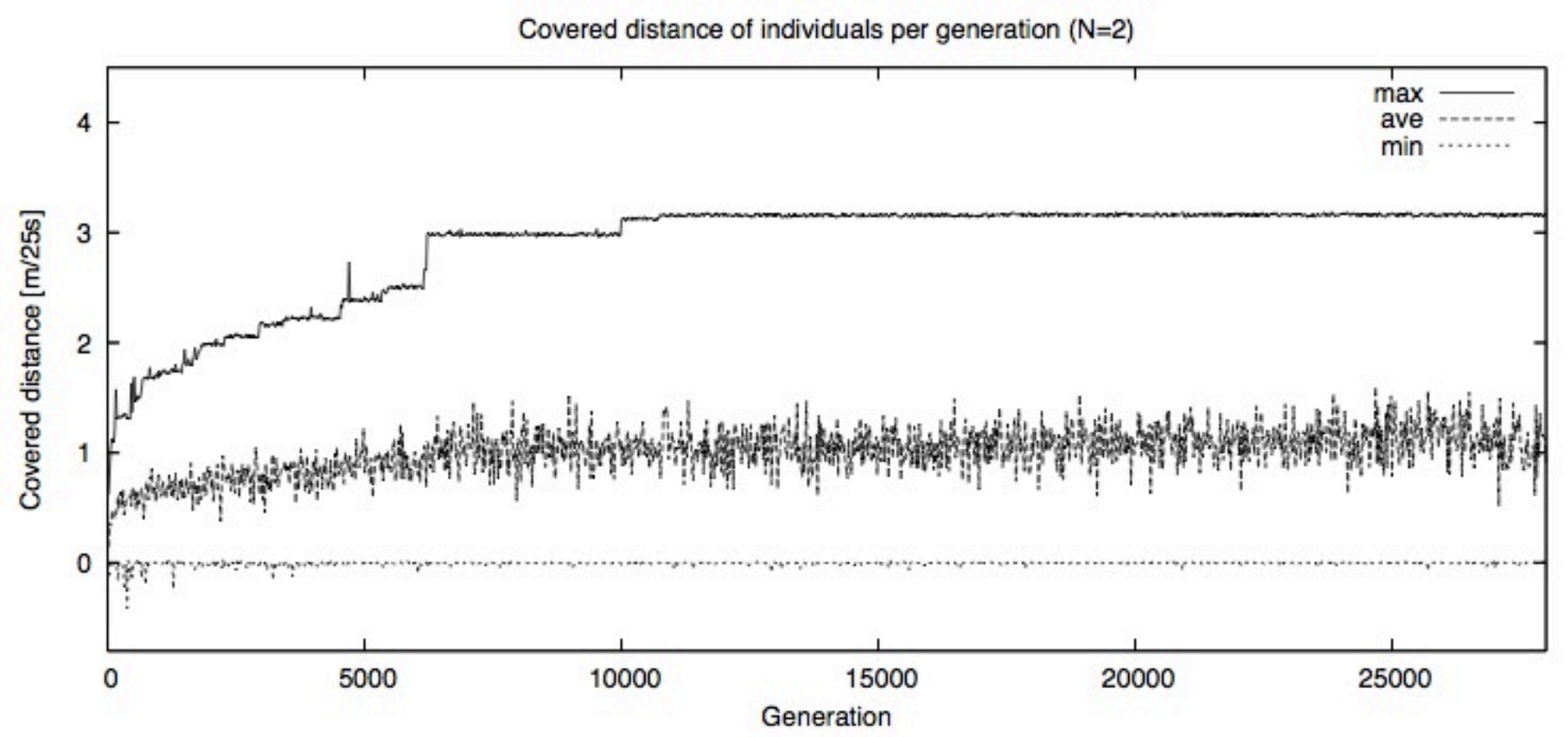
Cyclic Function

- Ergebnisse für N=1



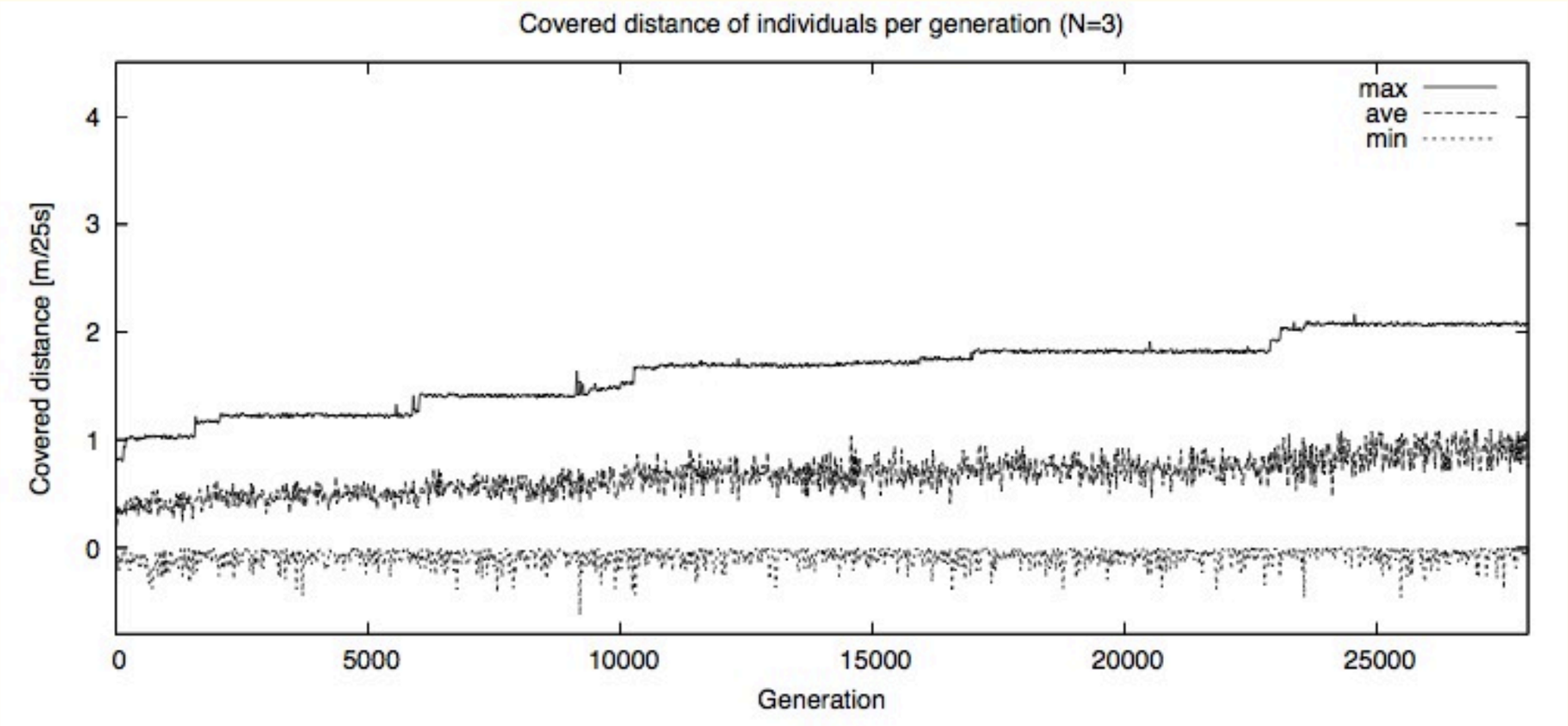
Cyclic Function

- Ergebnisse für N=2



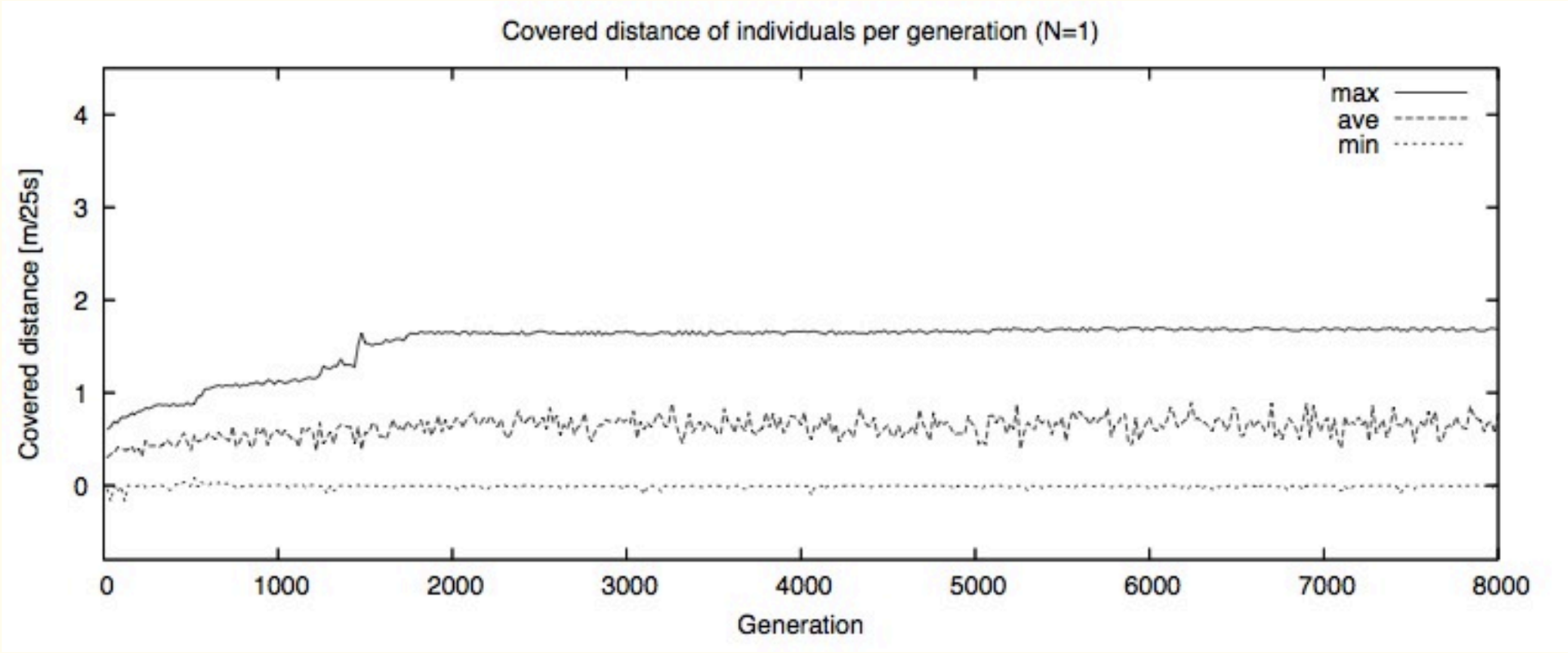
Cyclic Function

- Ergebnisse für N=3



Cyclic Function

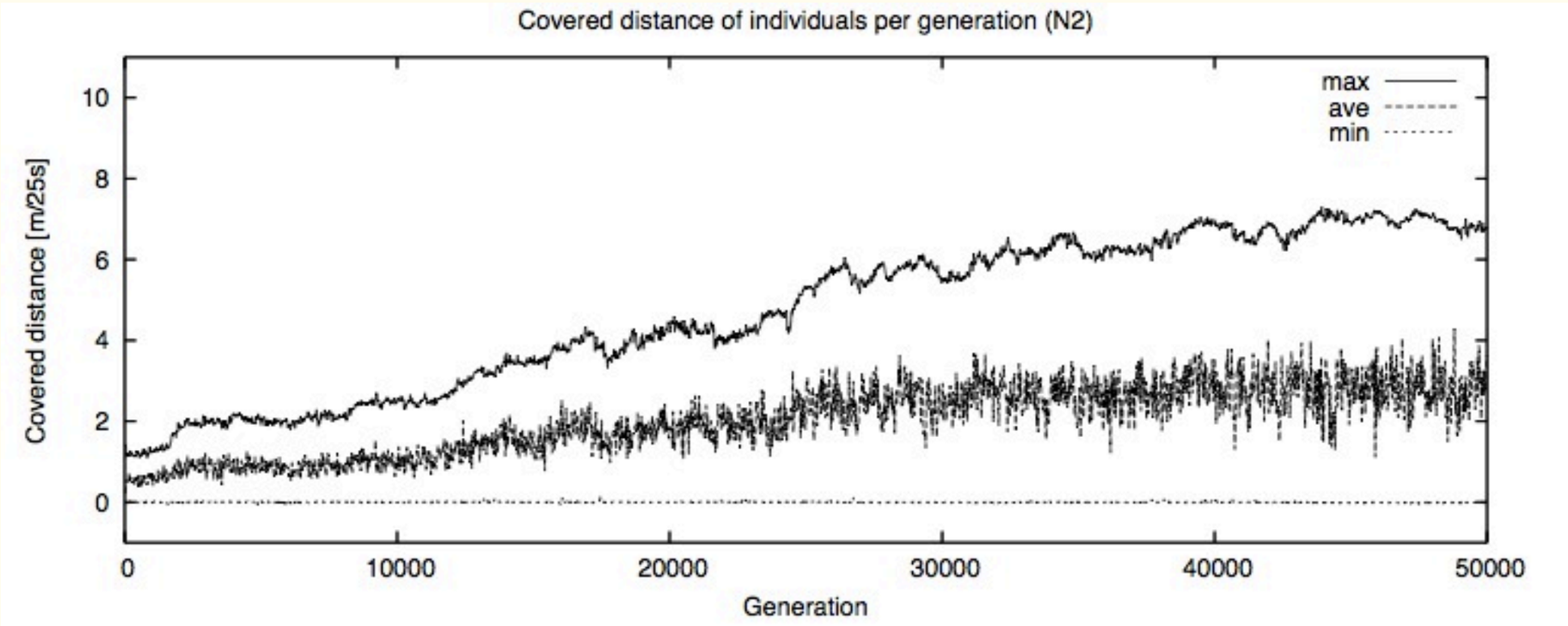
- inkrementelle Evolution N=1



- max = 1.74m

Cyclic Function

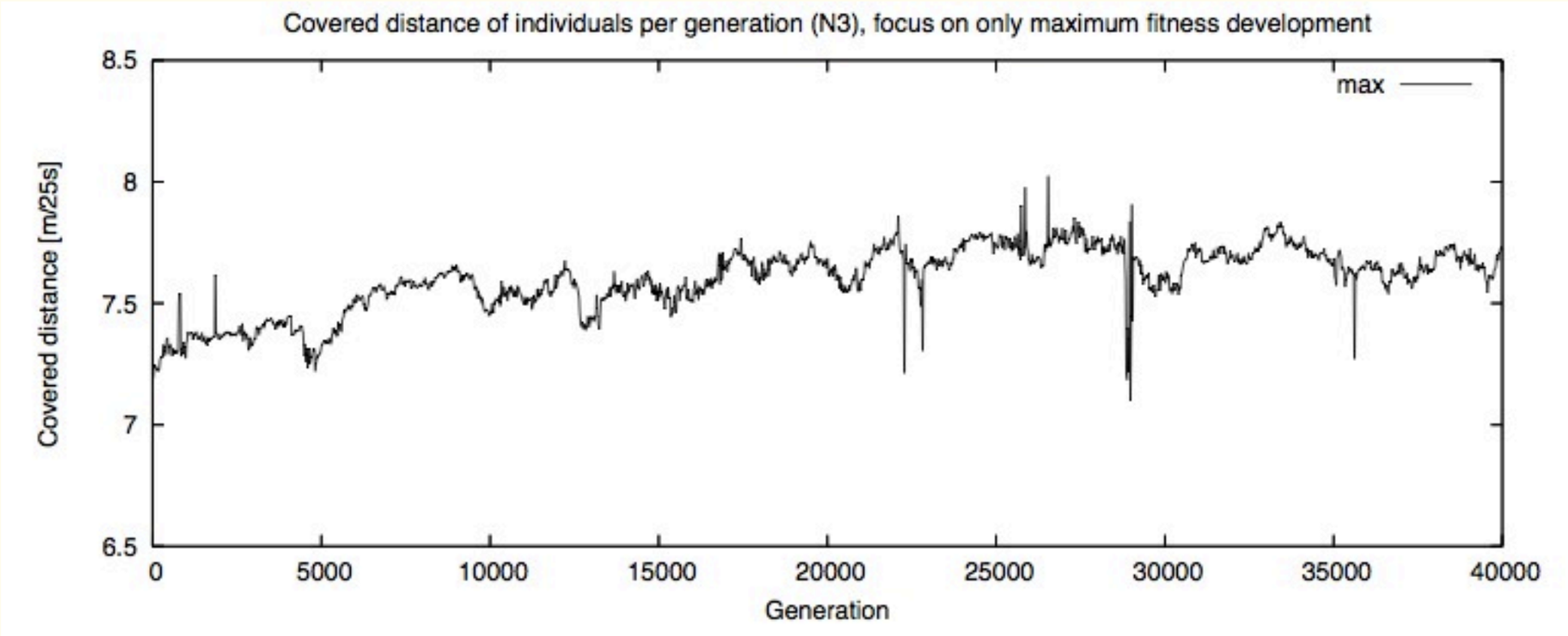
- inkrementelle Evolution N=2



- max = 7.43m

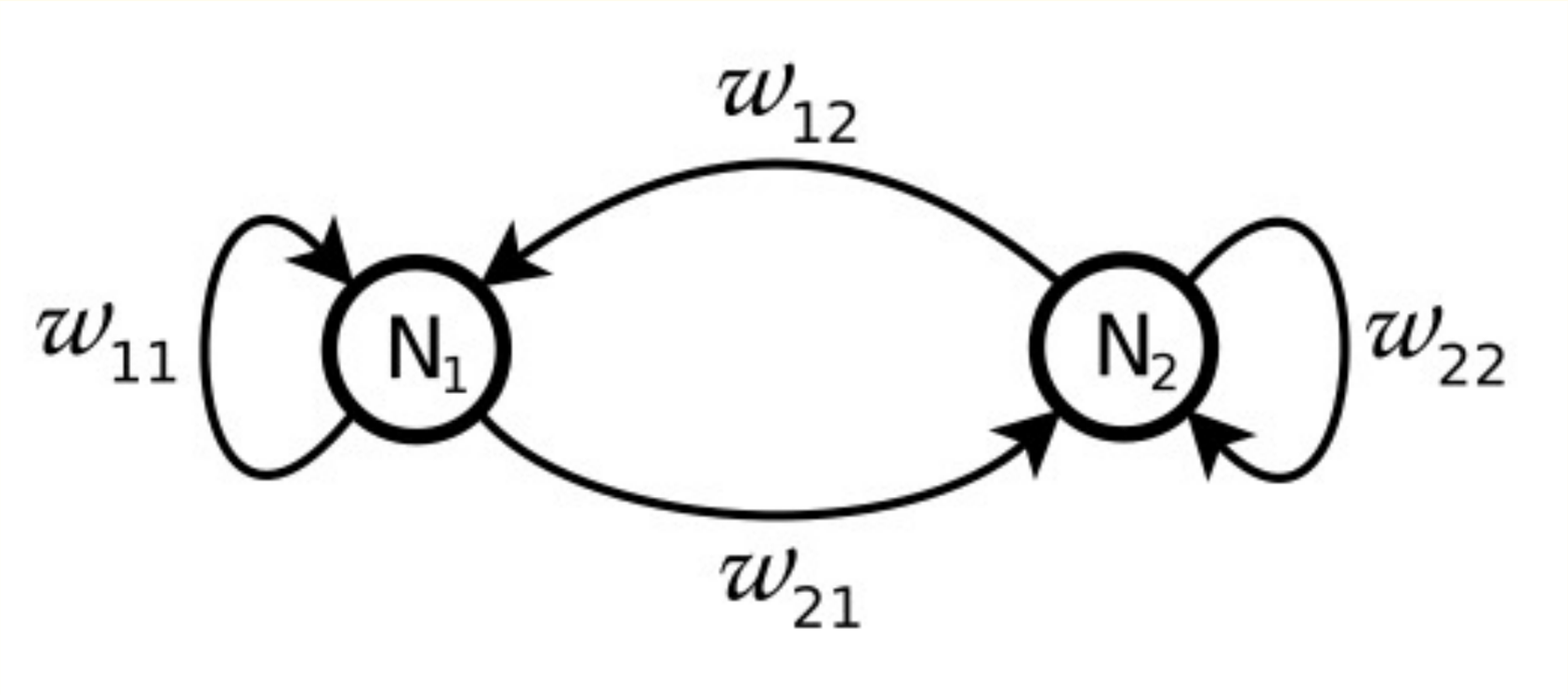
Cyclic Function

- inkrementelle Evolution N=3



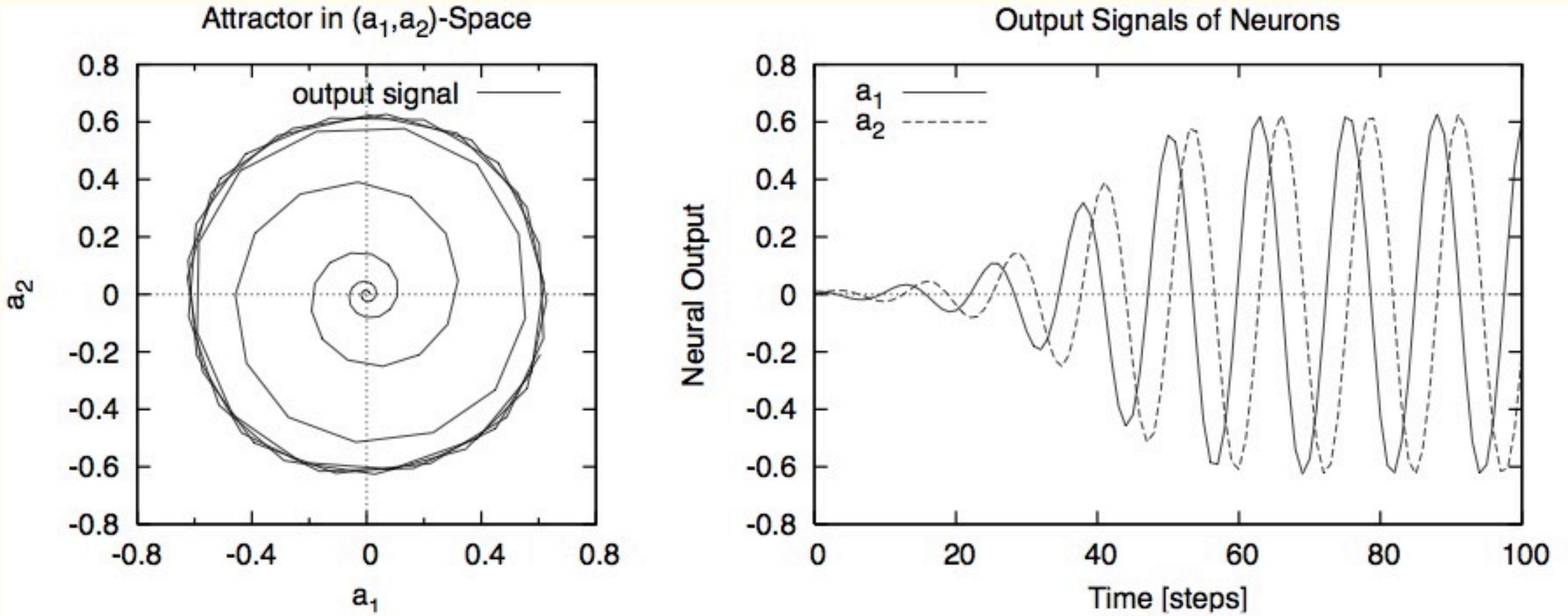
- max = 8.07m

Neural Osscillator

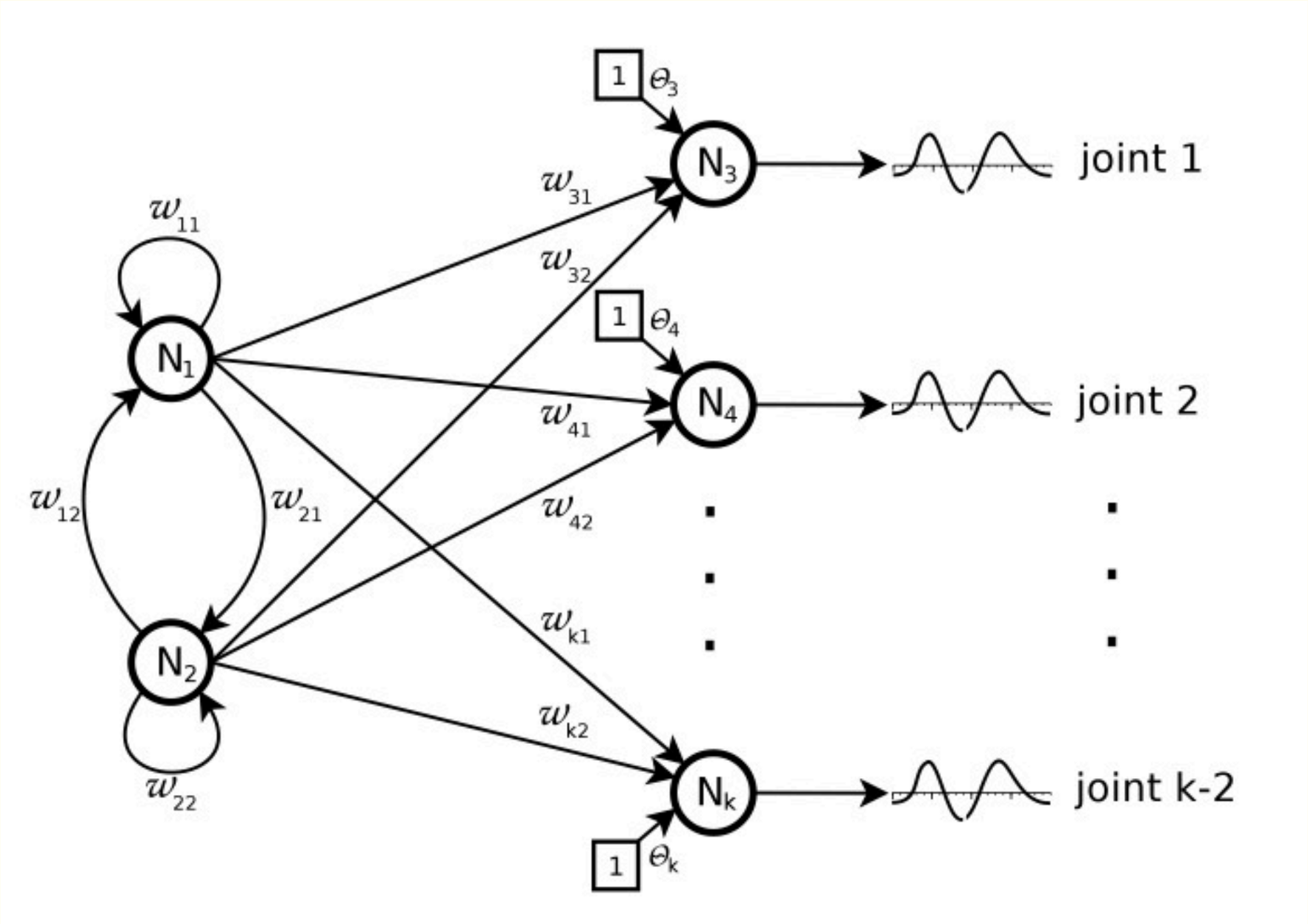


$$p = (\theta_1, \omega_{12}, \omega_{11}, \theta_2, \omega_{22}, \omega_{21}) \in \mathbb{R}^6$$

Neural Osscillator



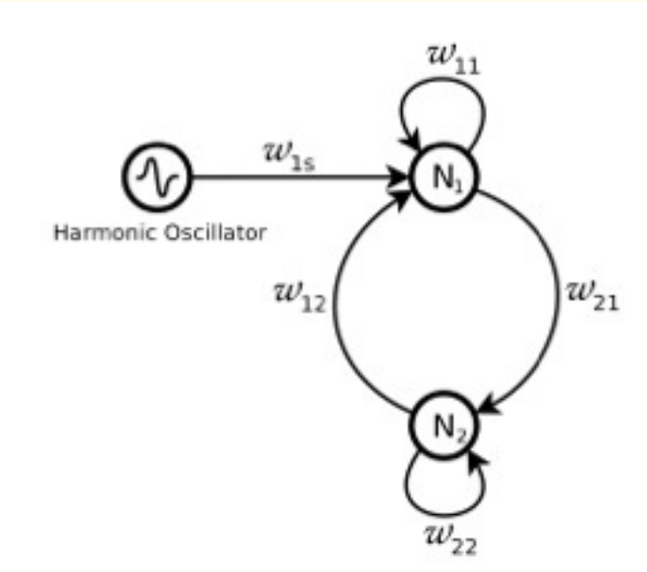
Neural Osscillator

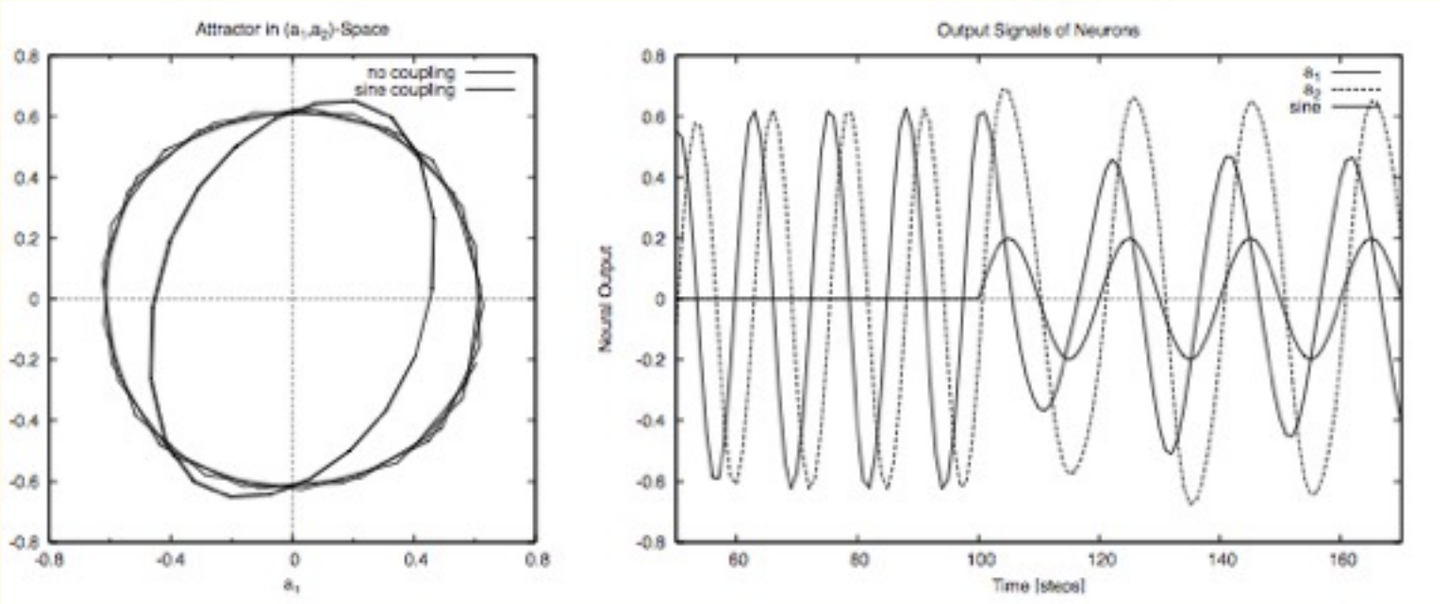


Probleme: Selektion und Integration nützlicher Informationen.

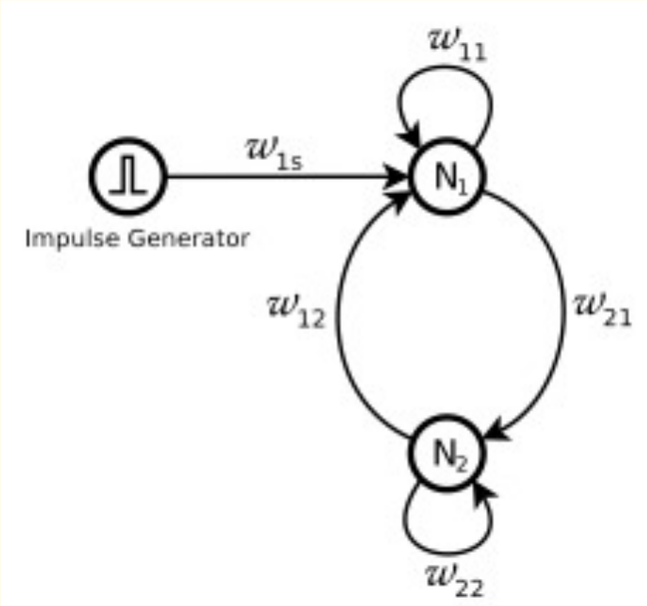
Neural Osscillator

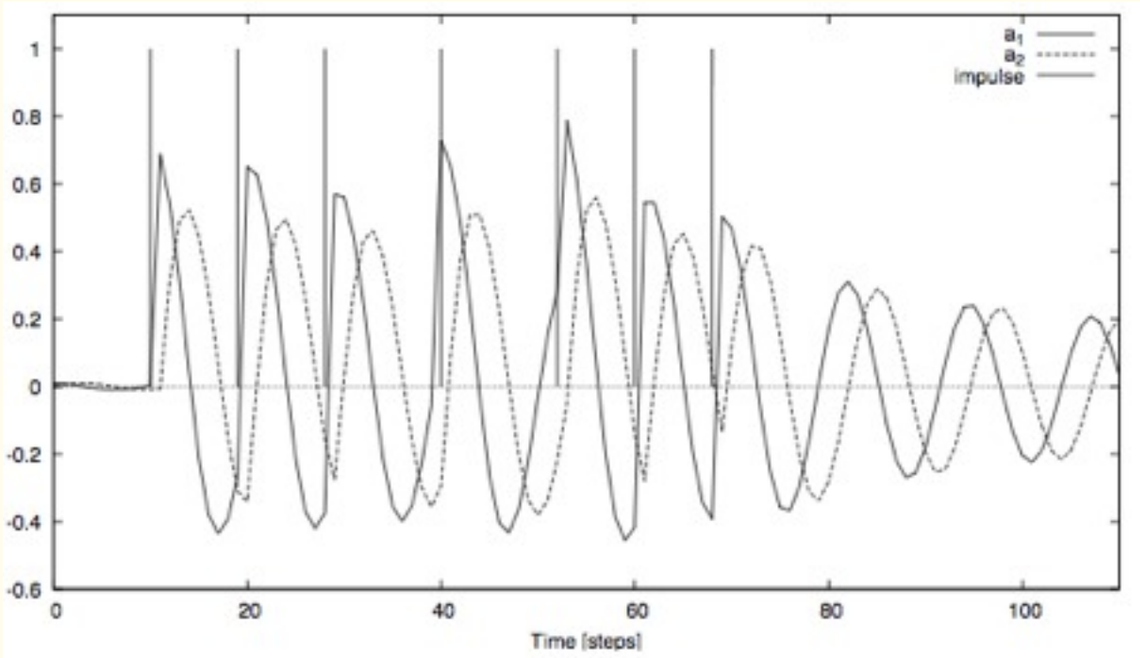
Harmonische Synchronisierung:





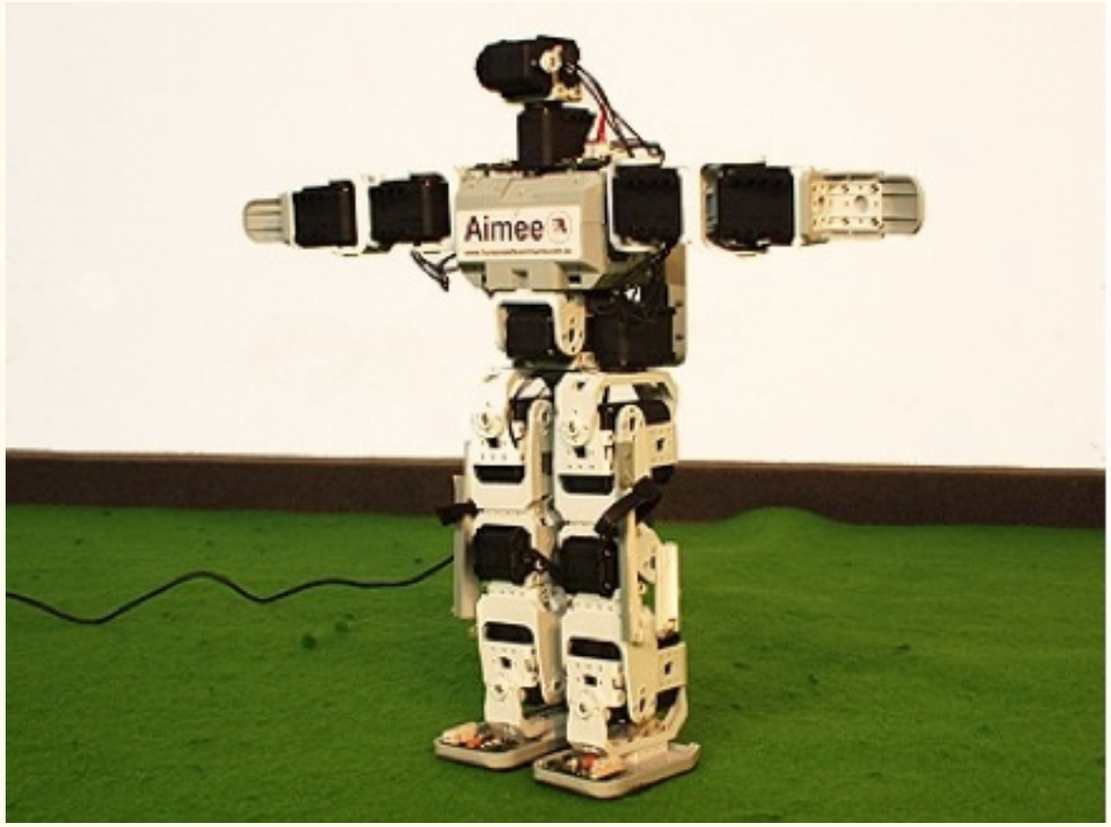
Impuls Synchronisierung:





Neural Osscillator

- 1 Joint = 3 Parameters
  = 4+3j
- Vereinfachungen = 34



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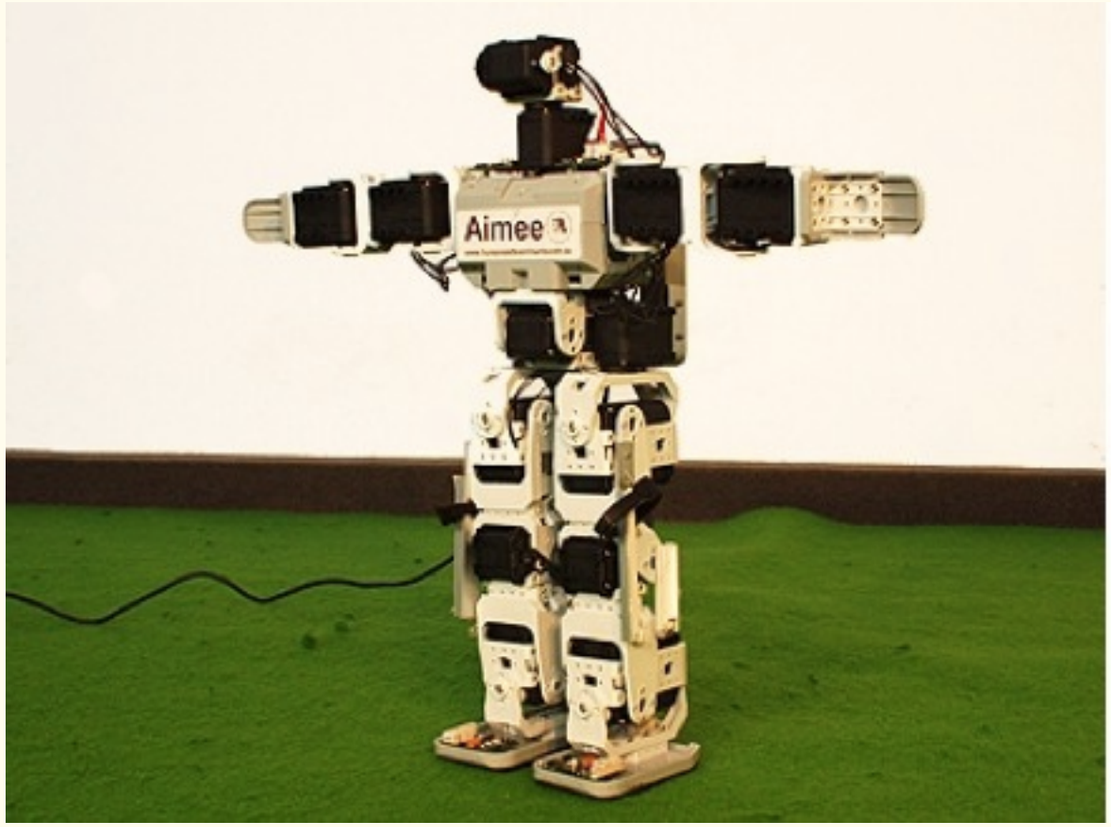
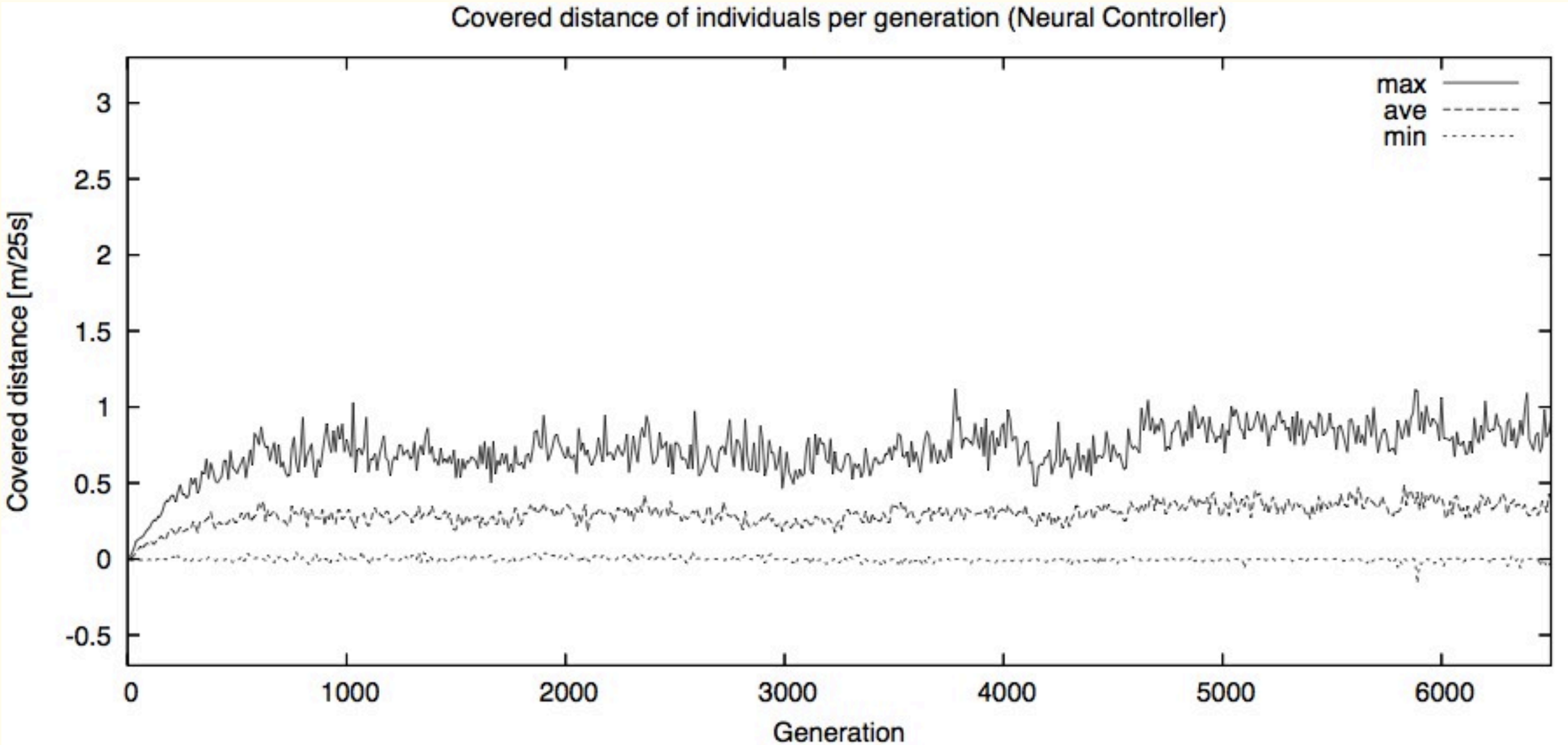


Parameter	Value
Episode Duration	25s
Population Size	50
Selection Size	15
Padding Type	Copy
Mutation Probability for an Individual[3]	0.9
Mutation Probability for a Gene	0.1
Gaussian Variance when Mutating a Gene	0.01

Neural Osscillator



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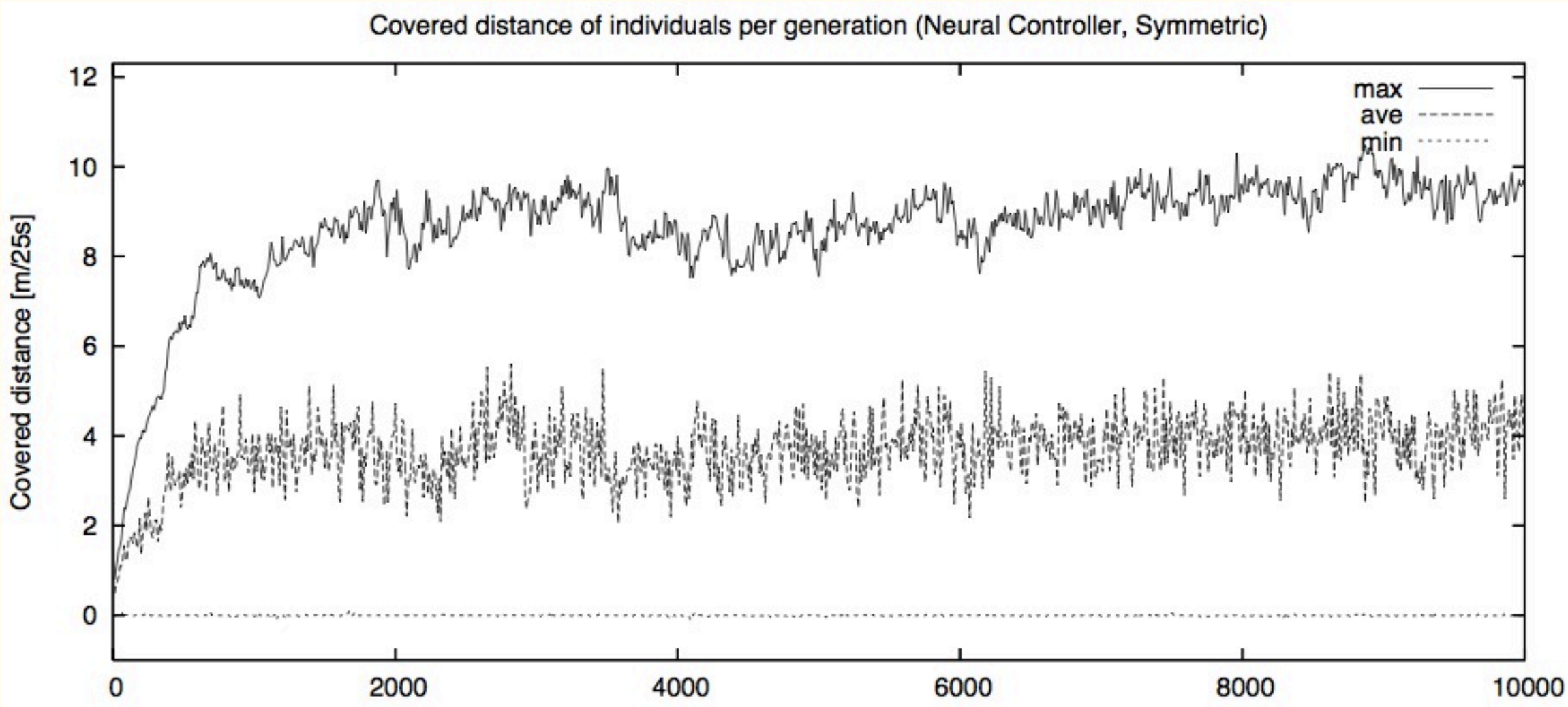

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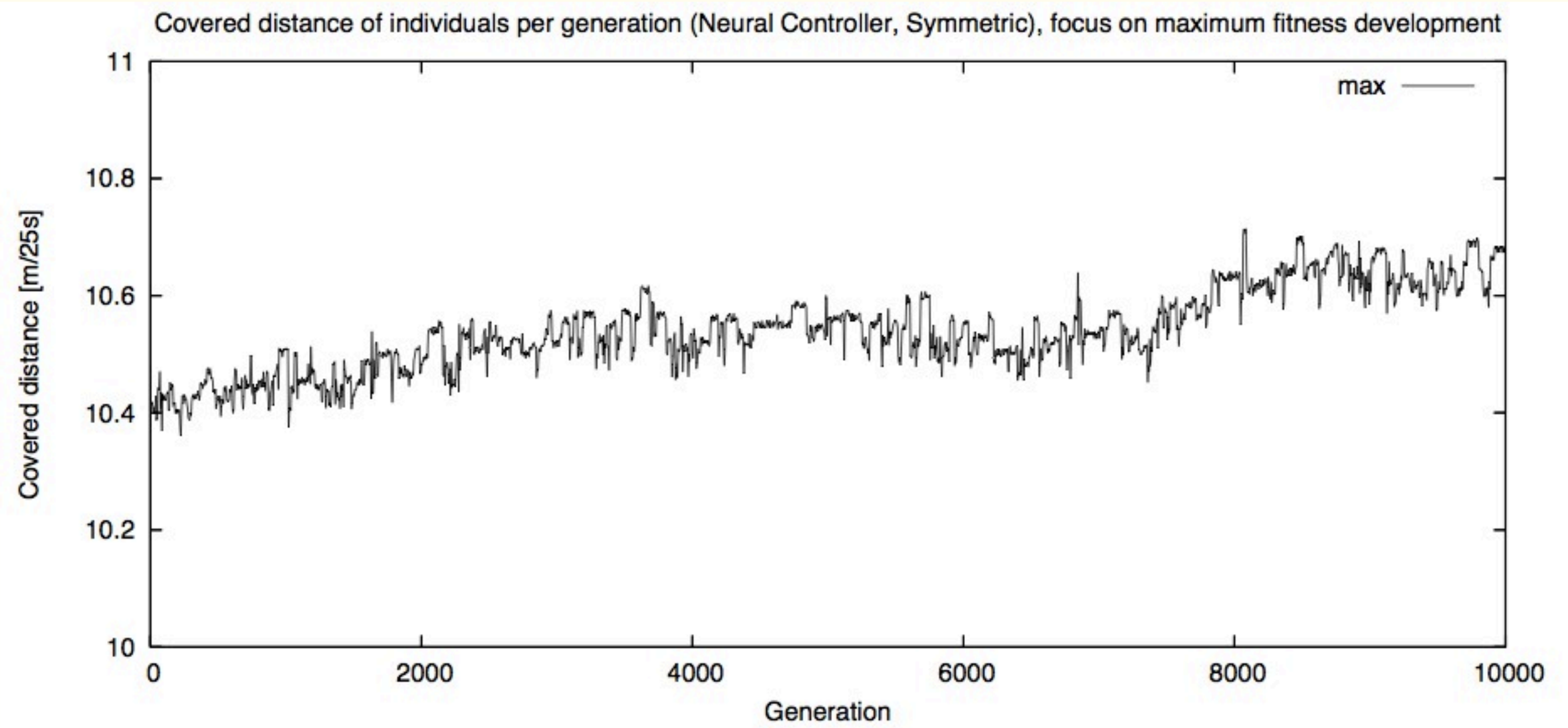
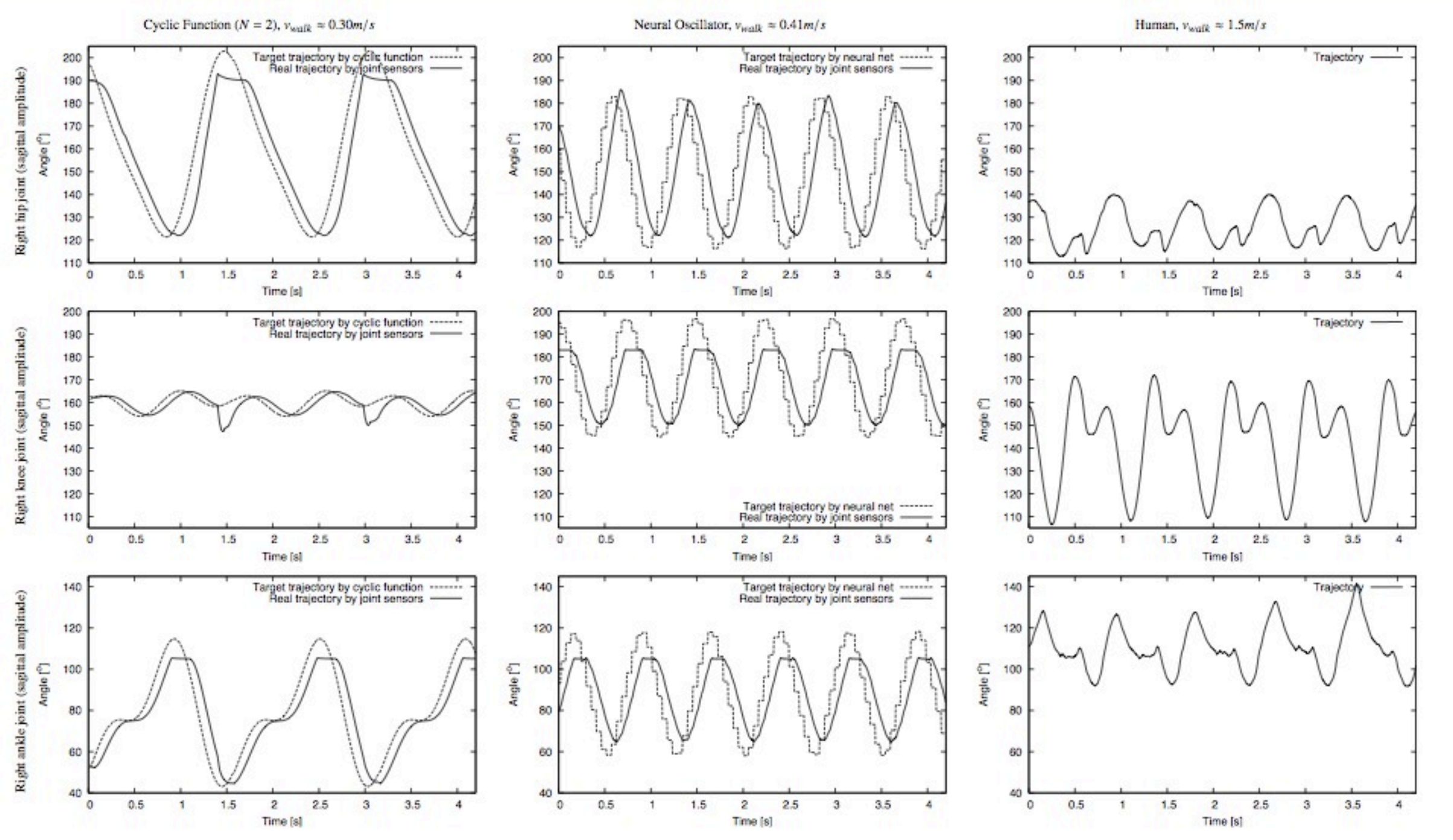


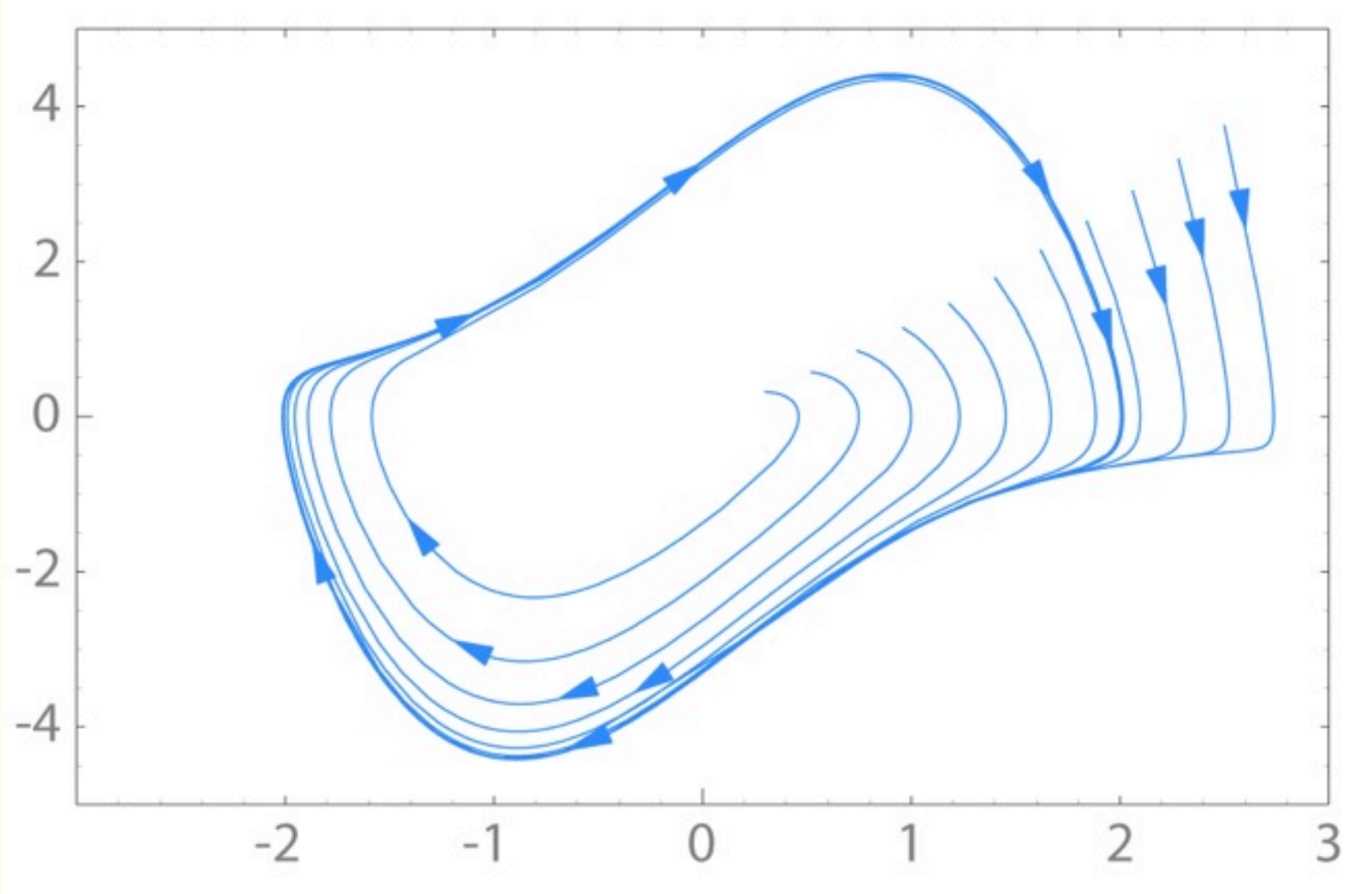
Neural Osscillator



limit cycle walking

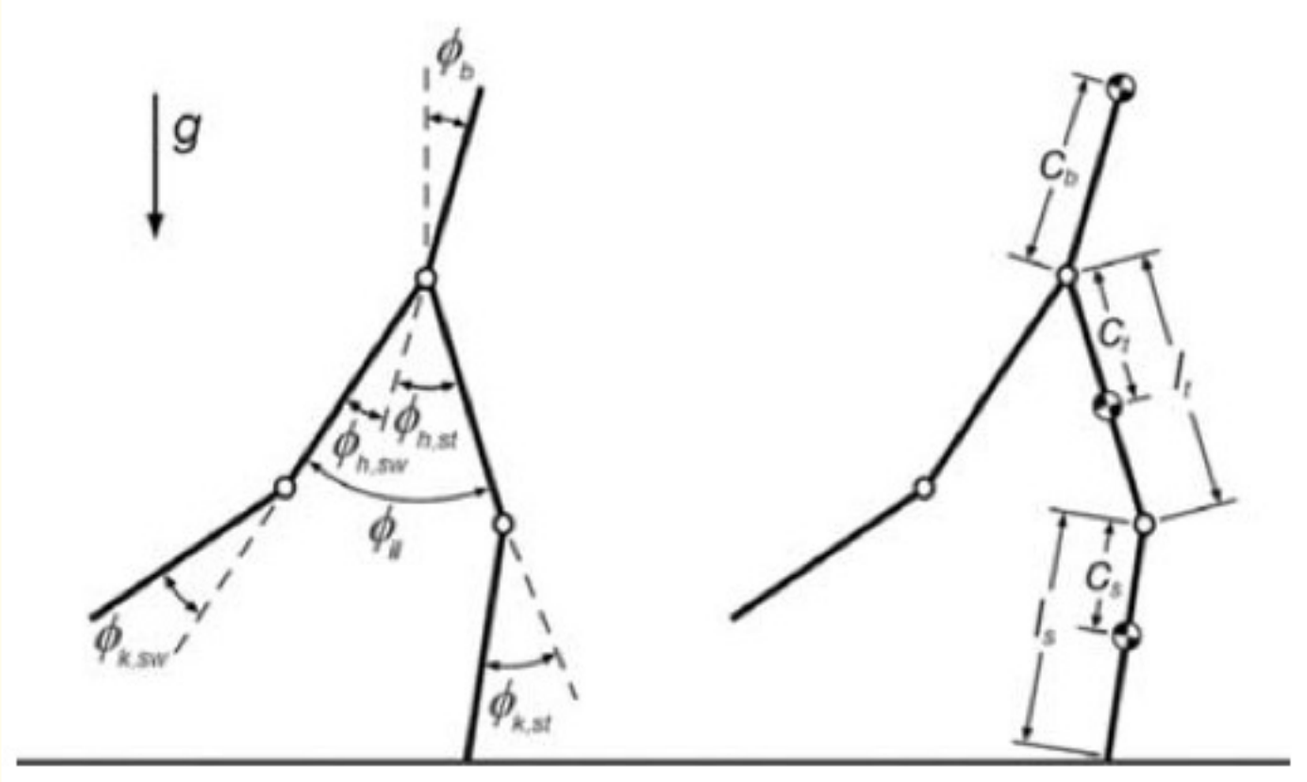
limit cycle walking

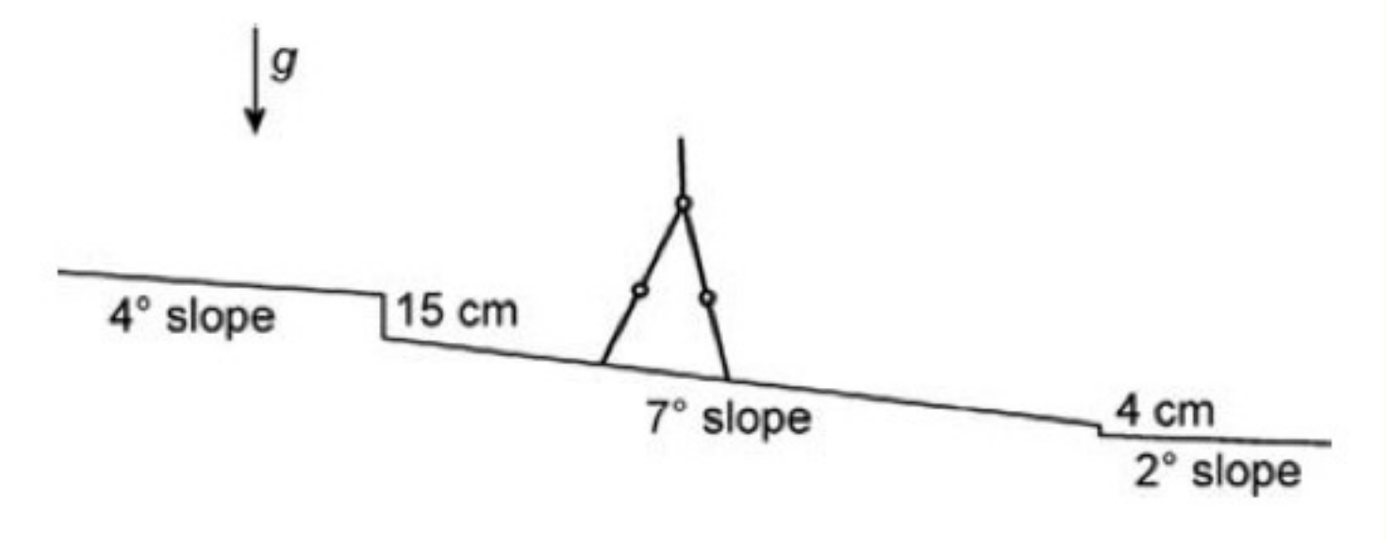
- hochgradig nichtlinear
- hoch dimensional
- verändert sich diskret
- reaktiver linearer Controller



limit cycle walking

- Standbein:
  - PD: proportional-derivative
- Schwungbein:
  - 4 Modelle





limit cycle walking

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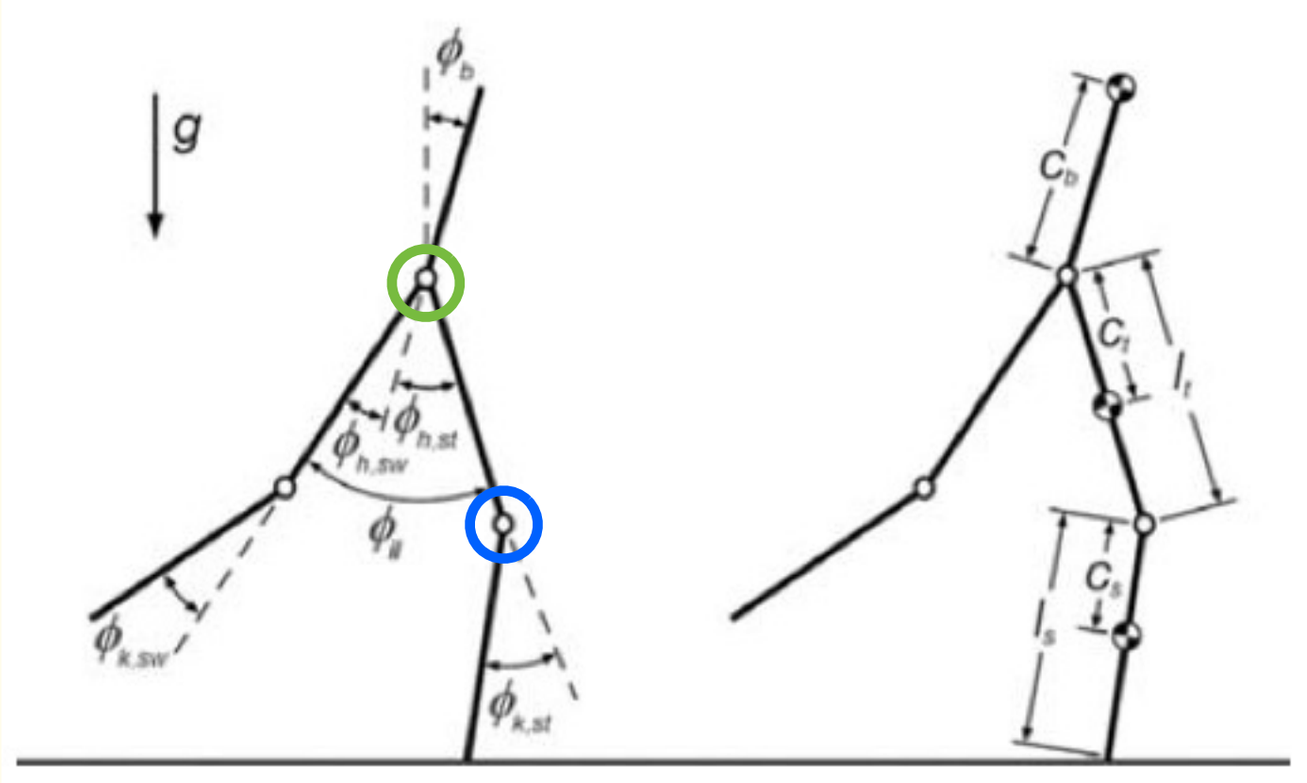
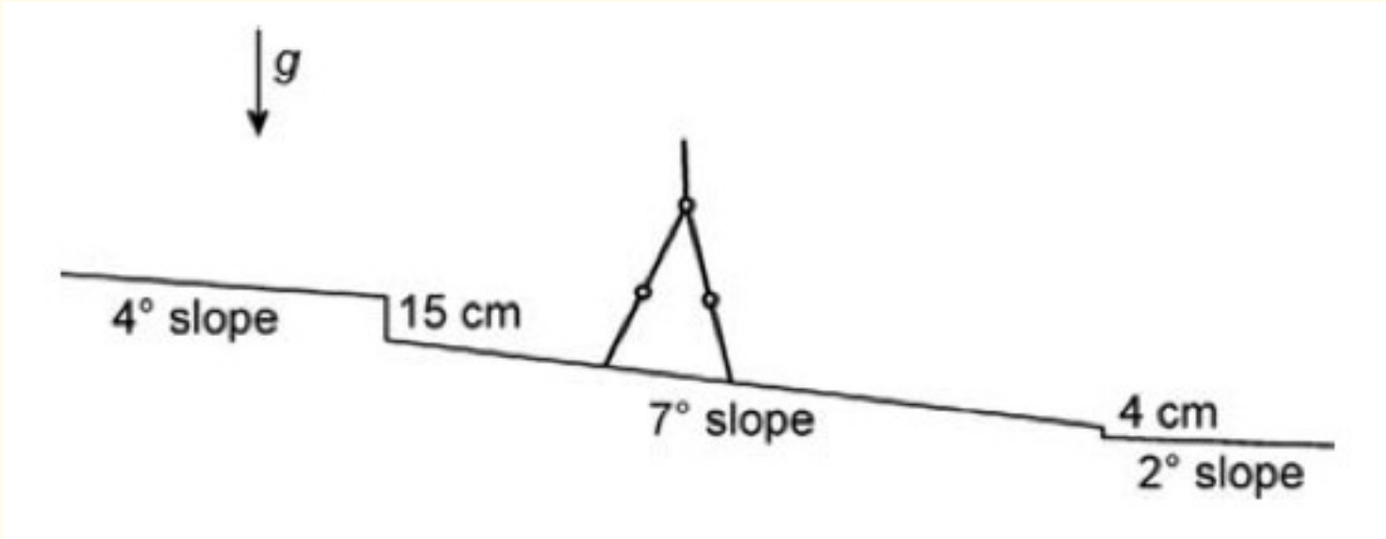


$$\tau_{h,st} = k_{p,body}\phi_b + k_{d,body}\dot{\phi}_b - \tau_{h,sw}$$

$$\tau_{k,st} = k_{p,knee}\phi_{k,st} + k_{d,knee}\dot{\phi}_{k,st}$$



limit cycle walking

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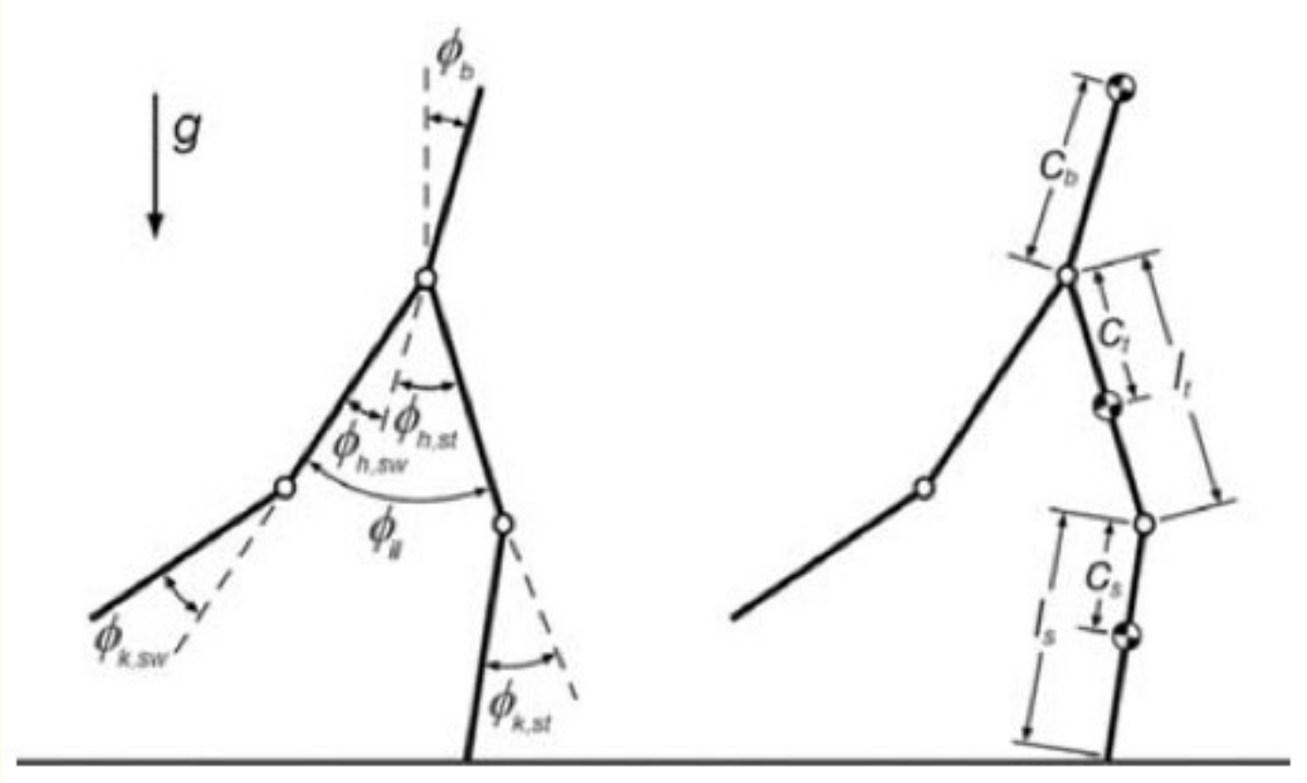
  - PD: proportional-derivative
- Schwungbein:
  - 4 Modelle



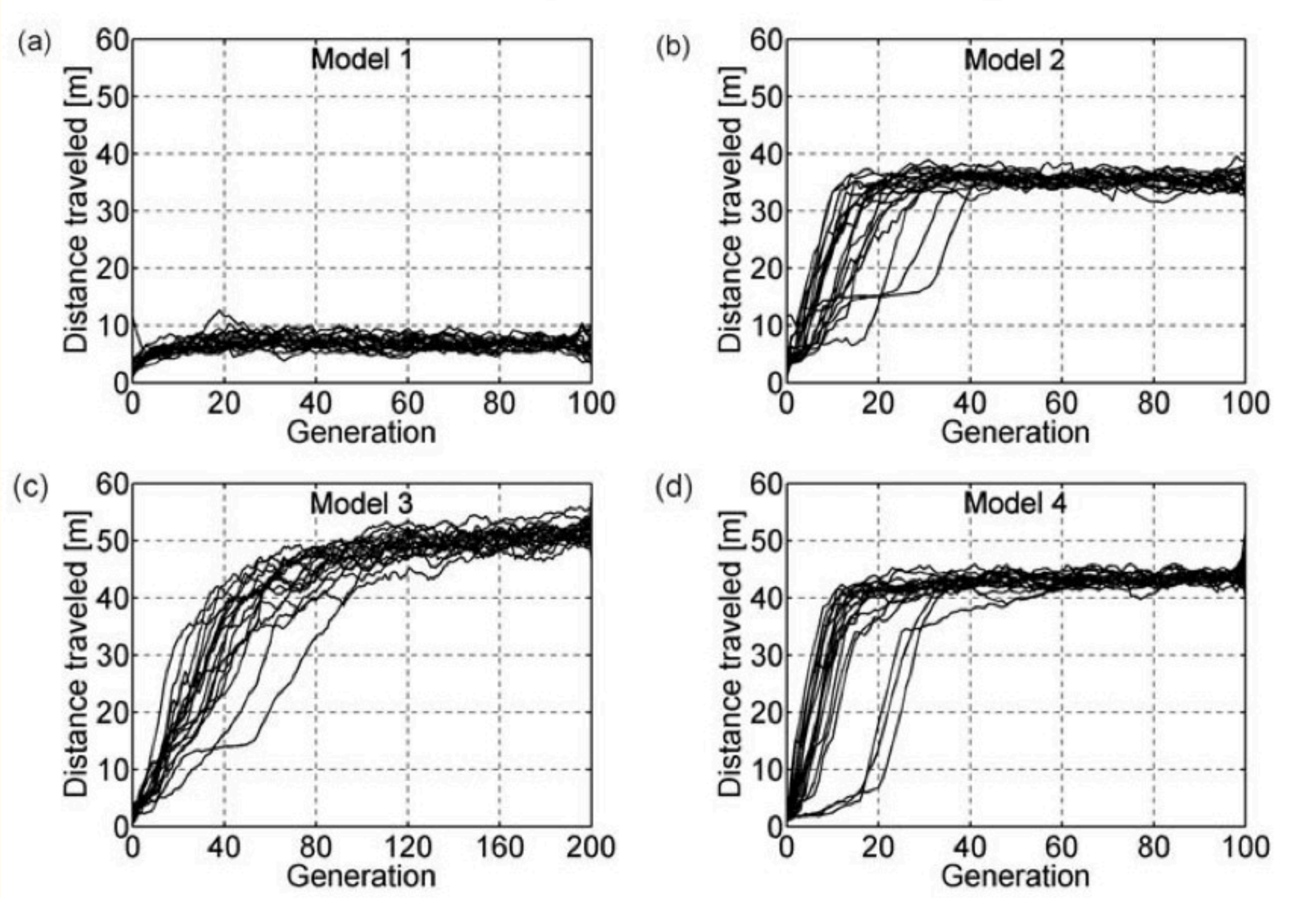
Model	Description	Activations	
1	Inter-leg PD control	$a_{h,sw} = w_1\phi_{ll} + w_2\dot{\phi}_{ll} + w_3$	(3)
		$a_{k,sw} = w_4\phi_{k,sw} + w_5\dot{\phi}_{k,sw}$	(4)
2	Swing thigh PD control	$a_{h,sw} = w_1\phi_{h,st} + w_2\phi_{h,sw} + w_3\dot{\phi}_{h,sw} + w_4$	(5)
		$a_{k,sw} = w_5\phi_{k,sw} + w_6\dot{\phi}_{k,sw}$	(6)
3	Fully interconnected, linear (FIL)	$a_{h,sw} = w_1\phi_{h,st} + w_2\phi_{h,sw} + w_3\phi_{k,sw} + w_4\dot{\phi}_{h,st} + w_5\dot{\phi}_{h,sw} + w_6\dot{\phi}_{k,sw} + w_7$	(7)
		$a_{k,sw} = w_8\phi_{h,st} + w_9\phi_{h,sw} + w_{10}\phi_{k,sw} + w_{11}\dot{\phi}_{h,st} + w_{12}\dot{\phi}_{h,sw} + w_{13}\dot{\phi}_{k,sw} + w_{14}$	(8)
4	FIL, no knee torque	$a_{h,sw} = w_1\phi_{h,st} + w_2\phi_{h,sw} + w_3\phi_{k,sw} + w_4\dot{\phi}_{h,st} + w_5\dot{\phi}_{h,sw} + w_6\dot{\phi}_{k,sw} + w_7$	(9)
		$a_{k,sw} = 0$	(10)

limit cycle walking

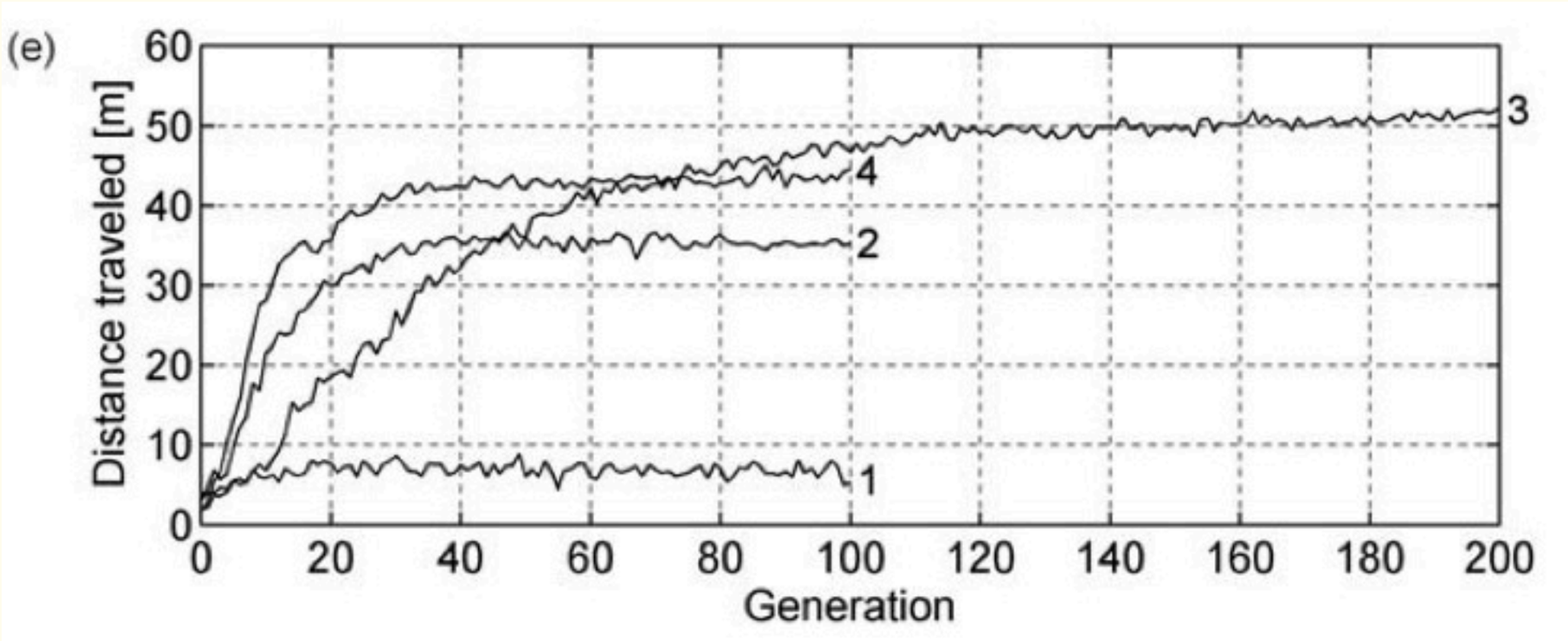
- Evolution
  - 100 zufällige Genotypen
  - Gen = Gewicht des Neurons
  - der beste aus der Generation überlebt 5 Generationen
  - Besten 15+5 => *5 + Mutation [0.2,0.05]
  - Fitness: Distanz + Energie

Model	Description	Activations	
1	Inter-leg PD control	$a_{h,sw} = w_1\phi_{ll} + w_2\dot{\phi}_{ll} + w_3$	(3)
		$a_{k,sw} = w_4\phi_{k,sw} + w_5\dot{\phi}_{k,sw}$	(4)
2	Swing thigh PD control	$a_{h,sw} = w_1\phi_{h,st} + w_2\phi_{h,sw} + w_3\dot{\phi}_{h,sw} + w_4$	(5)
		$a_{k,sw} = w_5\phi_{k,sw} + w_6\dot{\phi}_{k,sw}$	(6)
3	Fully interconnected, linear (FIL)	$a_{h,sw} = w_1\phi_{h,st} + w_2\phi_{h,sw} + w_3\phi_{k,sw} + w_4\dot{\phi}_{h,st} + w_5\dot{\phi}_{h,sw} + w_6\dot{\phi}_{k,sw} + w_7$	(7)
		$a_{k,sw} = w_8\phi_{h,st} + w_9\phi_{h,sw} + w_{10}\phi_{k,sw} + w_{11}\dot{\phi}_{h,st} + w_{12}\dot{\phi}_{h,sw} + w_{13}\dot{\phi}_{k,sw} + w_{14}$	(8)
4	FIL, no knee torque	$a_{h,sw} = w_1\phi_{h,st} + w_2\phi_{h,sw} + w_3\phi_{k,sw} + w_4\dot{\phi}_{h,st} + w_5\dot{\phi}_{h,sw} + w_6\dot{\phi}_{k,sw} + w_7$	(9)
		$a_{k,sw} = 0$	(10)

limit cycle walking

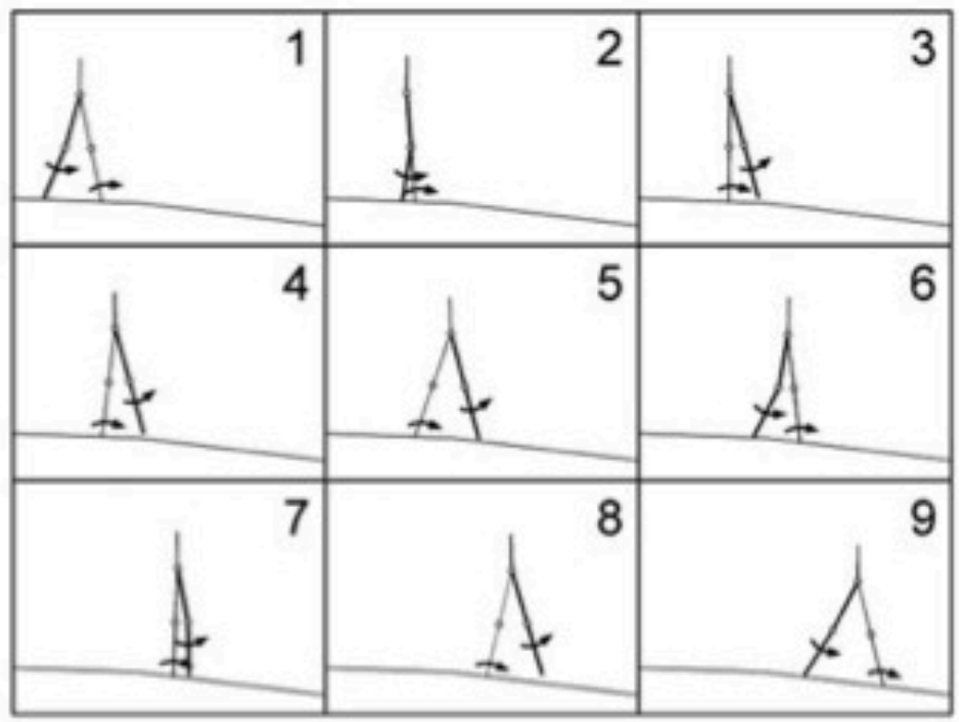


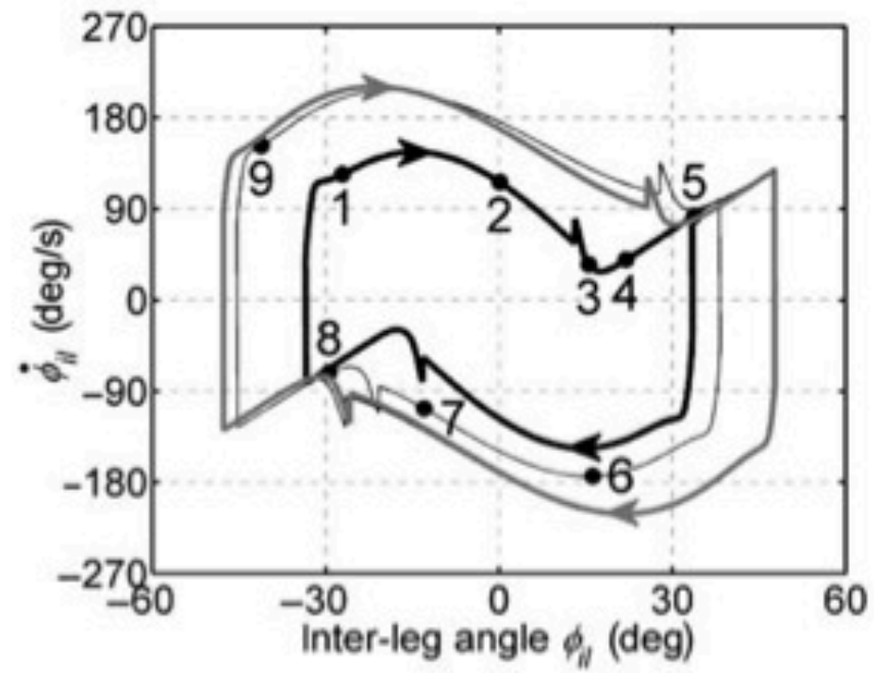
limit cycle walking

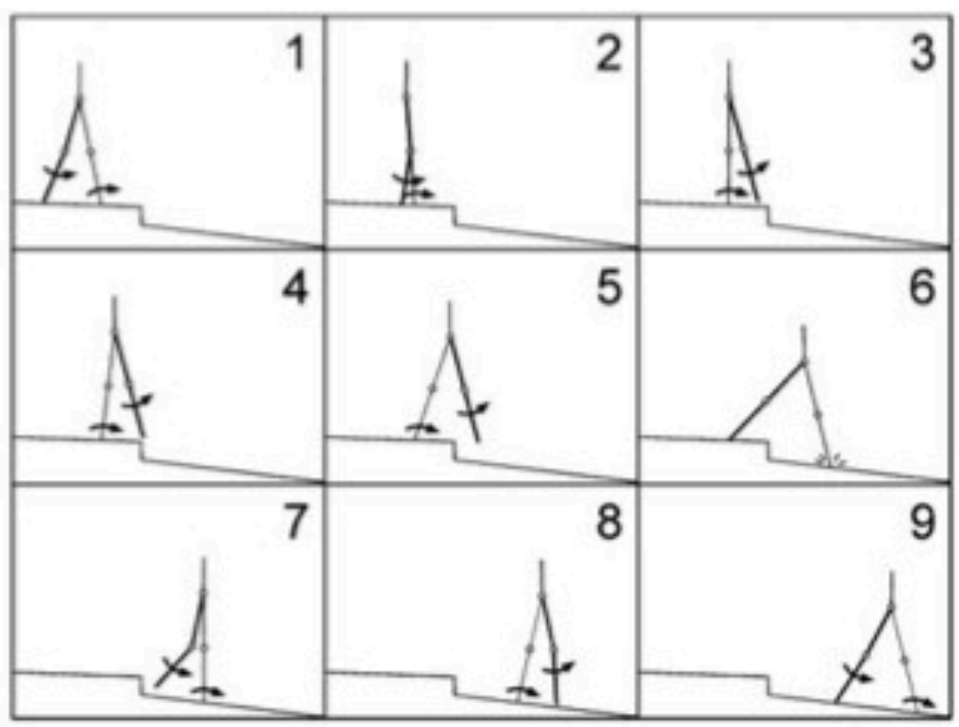


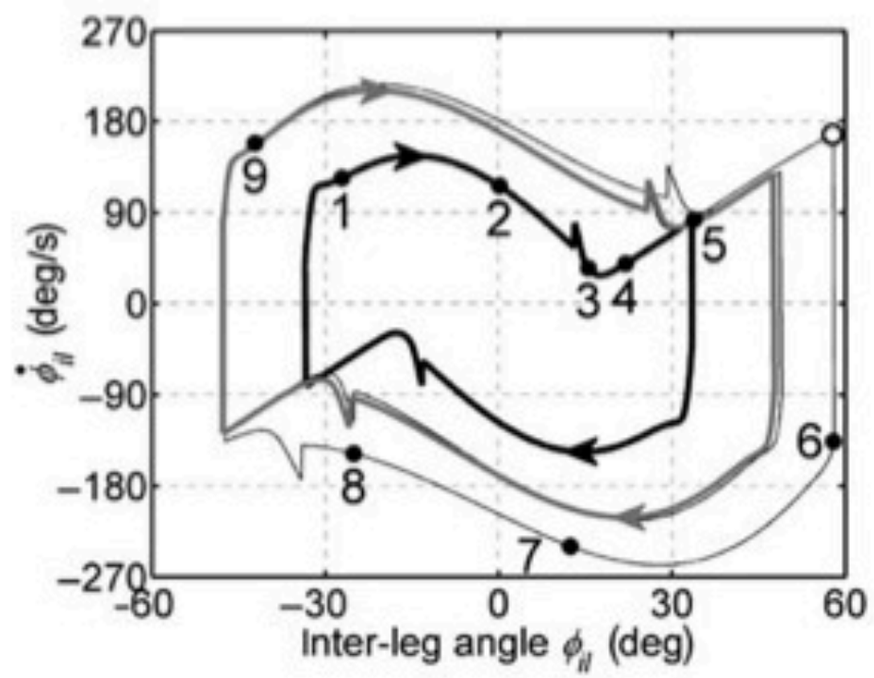
Model	Description	Activations	
1	Inter-leg PD control	$a_{h,sw} = w_1\phi_{il} + w_2\dot{\phi}_{il} + w_3$	(3)
		$a_{k,sw} = w_4\phi_{k,sw} + w_5\dot{\phi}_{k,sw}$	(4)
2	Swing thigh PD control	$a_{h,sw} = w_1\phi_{h,st} + w_2\phi_{h,sw} + w_3\dot{\phi}_{h,sw} + w_4$	(5)
		$a_{k,sw} = w_5\phi_{k,sw} + w_6\dot{\phi}_{k,sw}$	(6)
3	Fully interconnected, linear (FIL)	$a_{h,sw} = w_1\phi_{h,st} + w_2\phi_{h,sw} + w_3\phi_{k,sw} + w_4\dot{\phi}_{h,st} + w_5\dot{\phi}_{h,sw} + w_6\dot{\phi}_{k,sw} + w_7$	(7)
		$a_{k,sw} = w_8\phi_{h,st} + w_9\phi_{h,sw} + w_{10}\phi_{k,sw} + w_{11}\dot{\phi}_{h,st} + w_{12}\dot{\phi}_{h,sw} + w_{13}\dot{\phi}_{k,sw} + w_{14}$	(8)
4	FIL, no knee torque	$a_{h,sw} = w_1\phi_{h,st} + w_2\phi_{h,sw} + w_3\phi_{k,sw} + w_4\dot{\phi}_{h,st} + w_5\dot{\phi}_{h,sw} + w_6\dot{\phi}_{k,sw} + w_7$	(9)
		$a_{k,sw} = 0$	(10)

limit cycle walking









Ende