Organic Fault-tolerant Robot Control Architecture

E. Maehle,
A. Al Homsey,
A. El Sayed Auf,
B. Jakimovski
S. Krannich

University of Lübeck
Institute of Computer Engineering

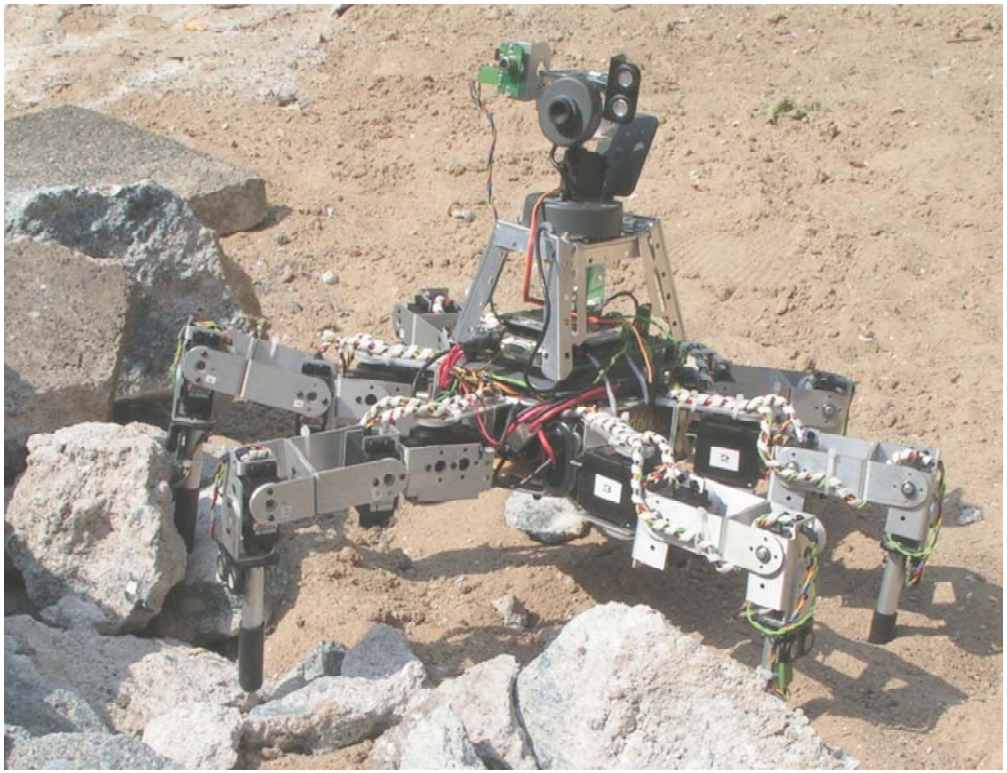
W. Brockmann,
A. Buschermöhle,
N. Rosemann

Institute of Computer Science
Computer Engineering Group

9th Colloquium *Organic Computing*
Augsburg

Motivation

Autonomous mobile robots in dangerous environments



unstructured,
dynamically changing
environment

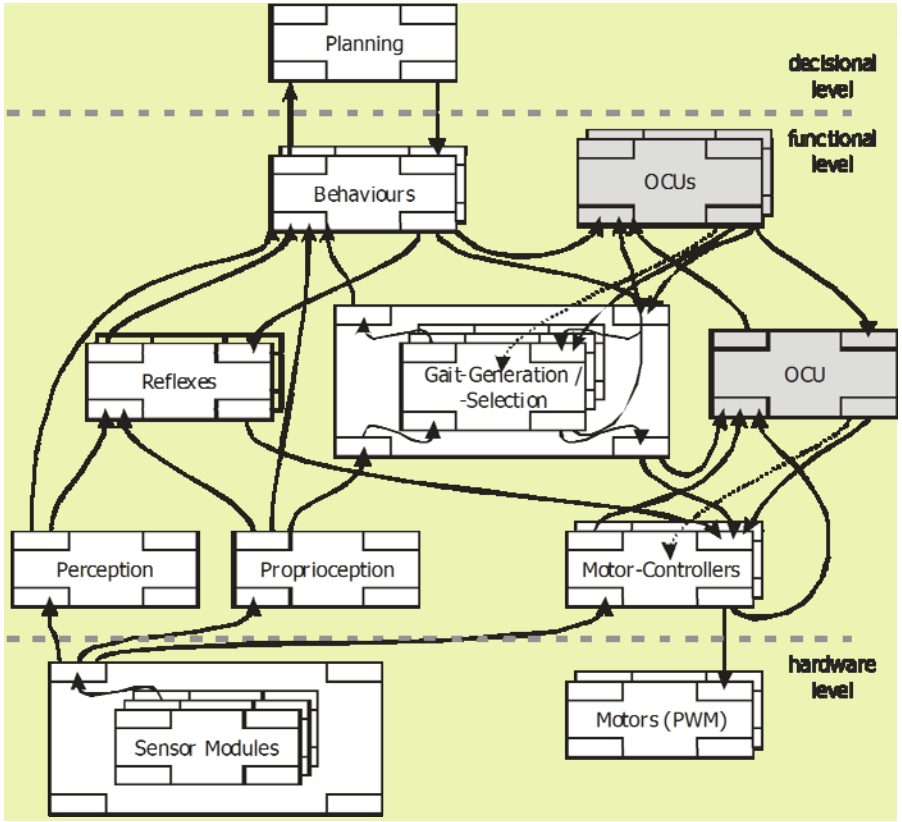
complex control systems

no explicit fault / world
model

-> fault-tolerance,
safety

-> engineering
bottleneck

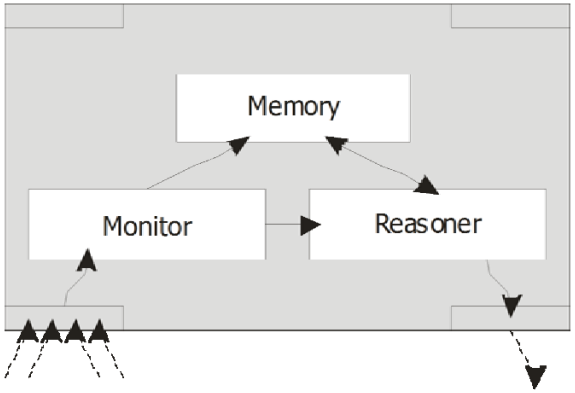
ORCA –
Organic Robot Control Architecture



BCU = Basic Control Unit

OCU = Organic Control Unit

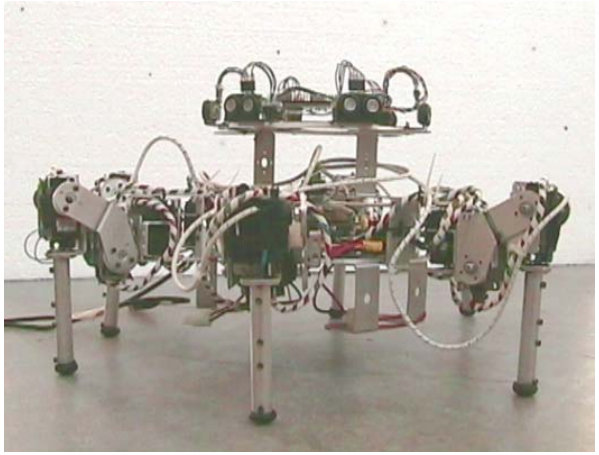
OCU-Architecture

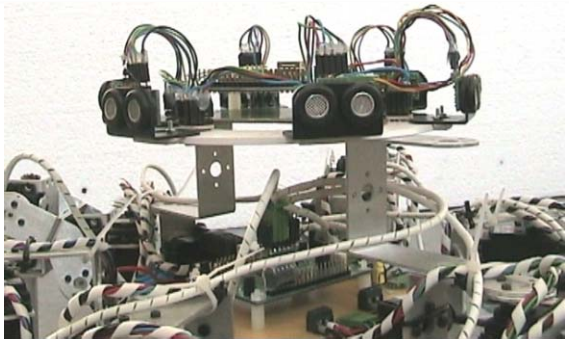


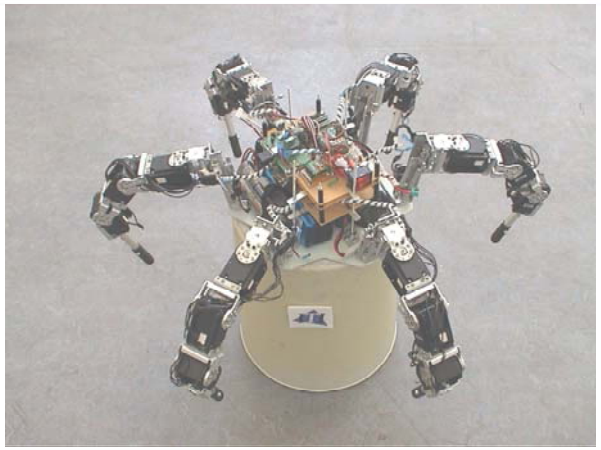
- Monitor: anomaly detection
- Memory: short term history (learning)
- Reasoner: hard real-time determination of a counteraction

→ Variant of Observer/Controller Architecture

Platform:
six-legged walking machine OSCAR







New Features:

- Stronger digital servos

- Feedback of internal servo states

- Enhanced lifting capacity

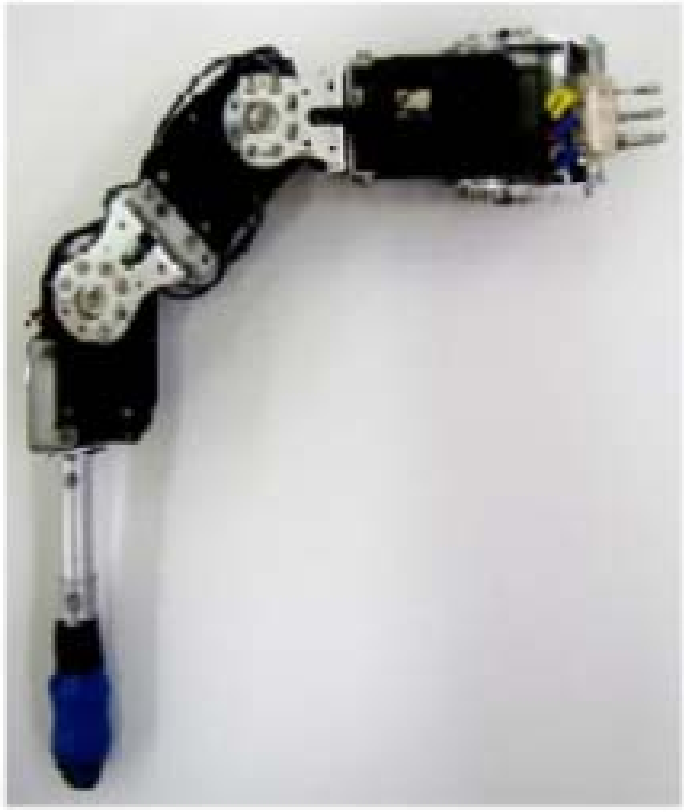
- Sensor turret

- Leg-(de)attachment

- More computational power

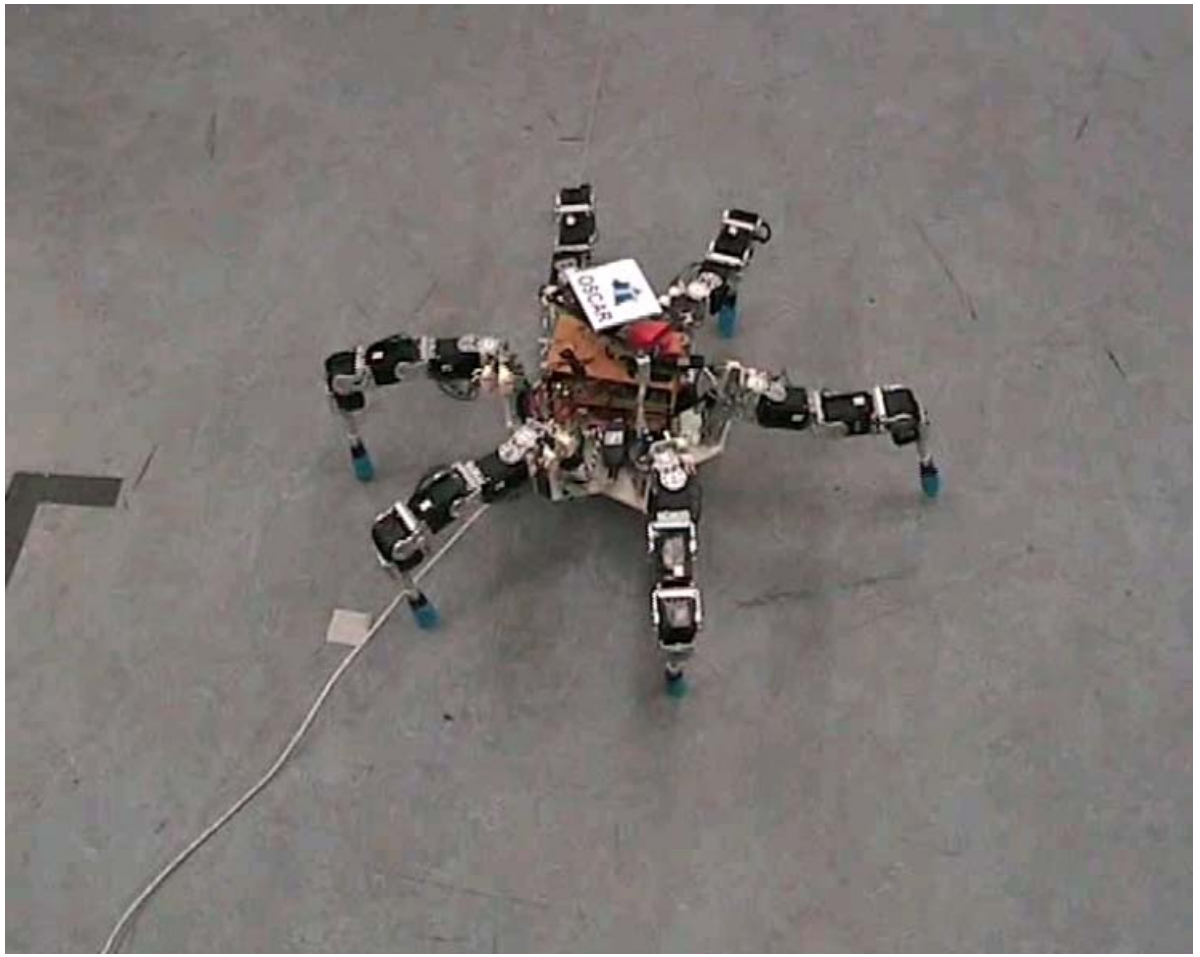
Robot Leg Amputation Mechanism (R-LEGAM)

(Patent pending)



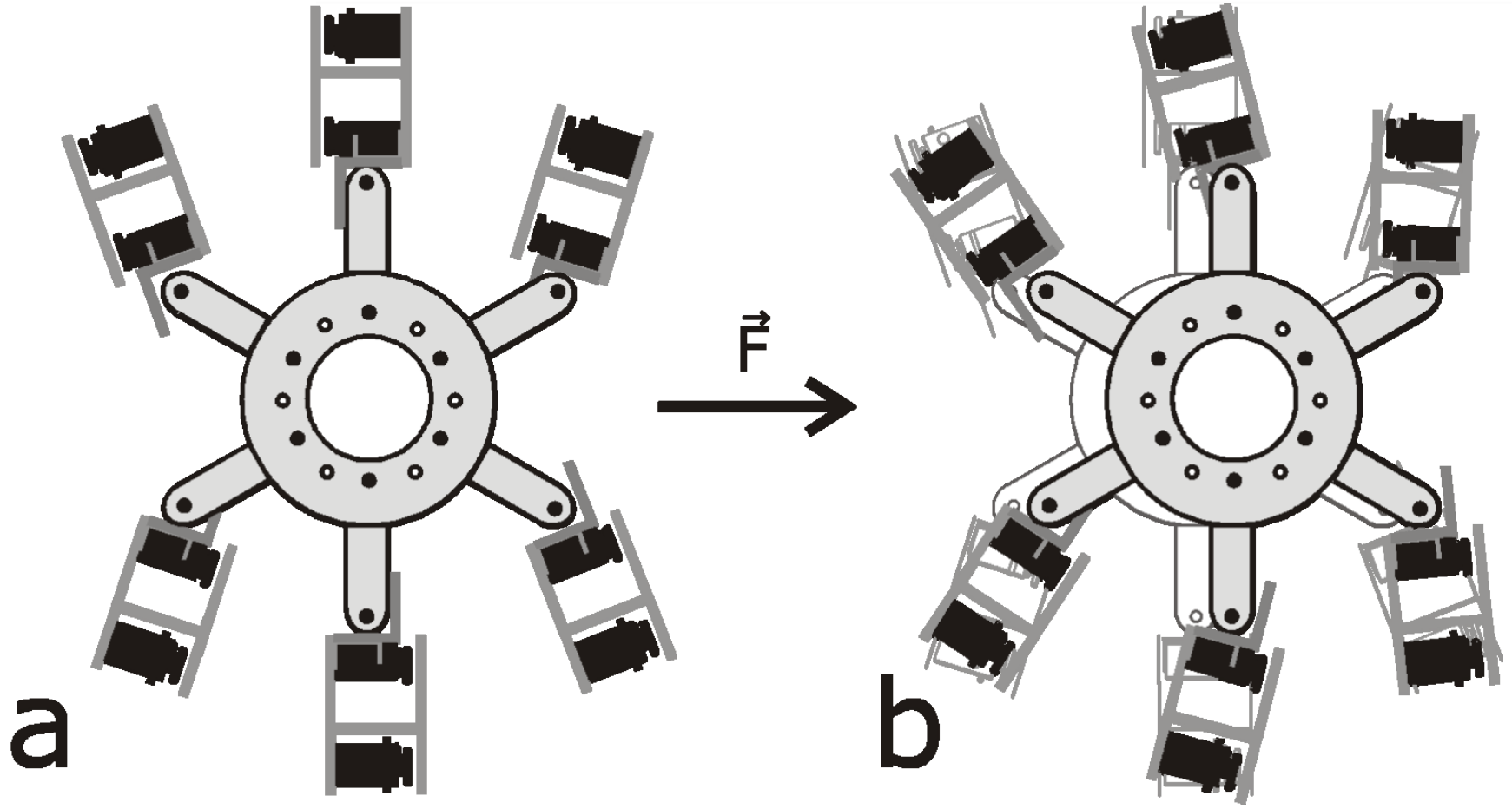
[1]

Robot Leg Amputation Mechanism (R-LEGAM) and SIRR (Swarm Intelligence for Robot Reconfiguration)



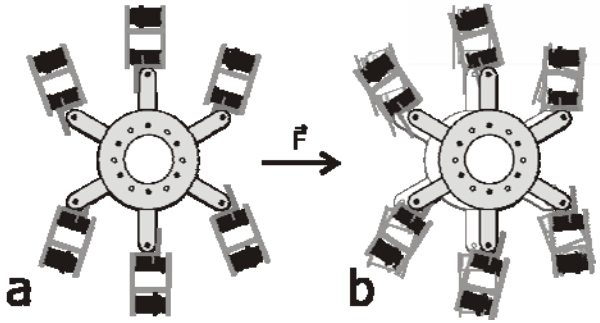
[1]

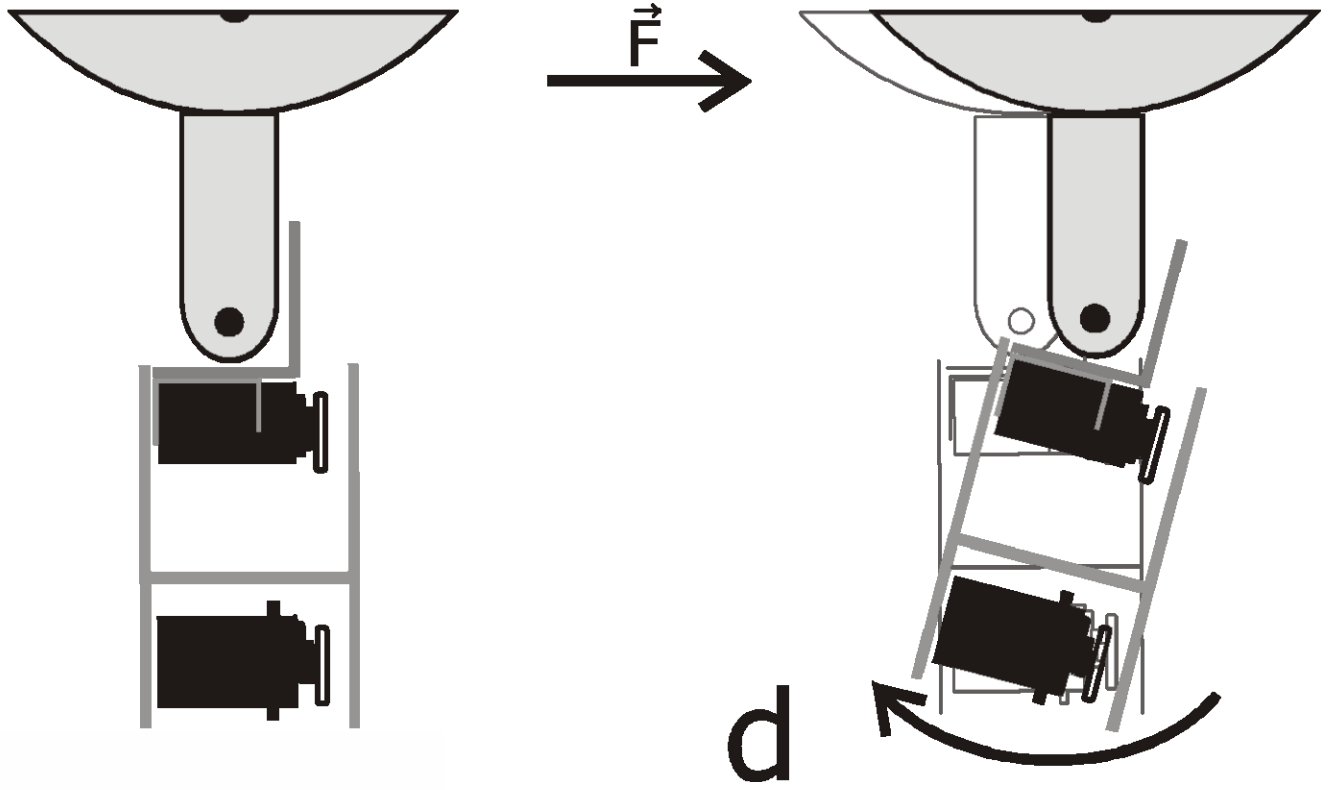
Emergent Reaction to Externally Acting Forces



[2]

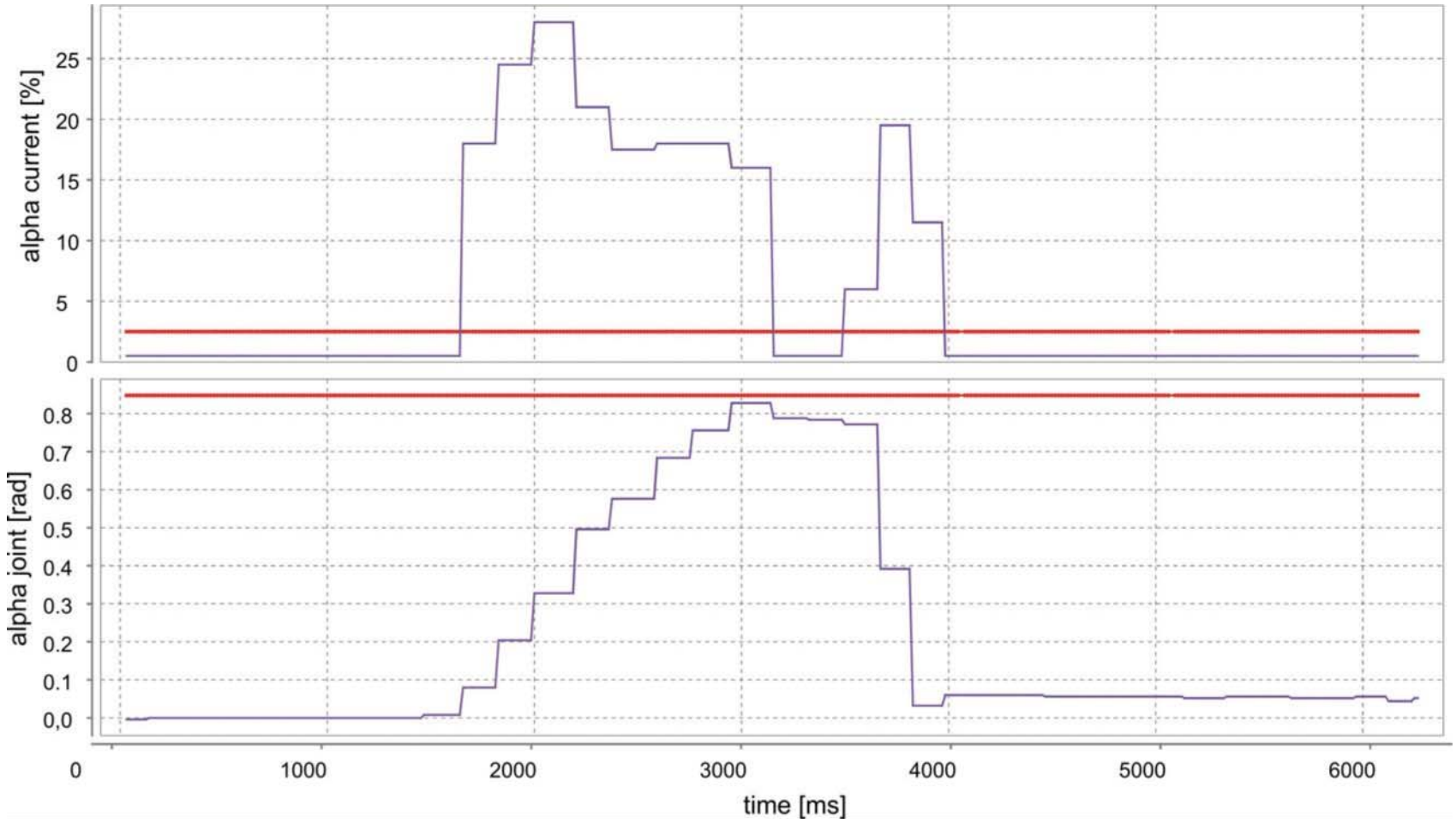
Emergent Reaction to Externally Acting Forces





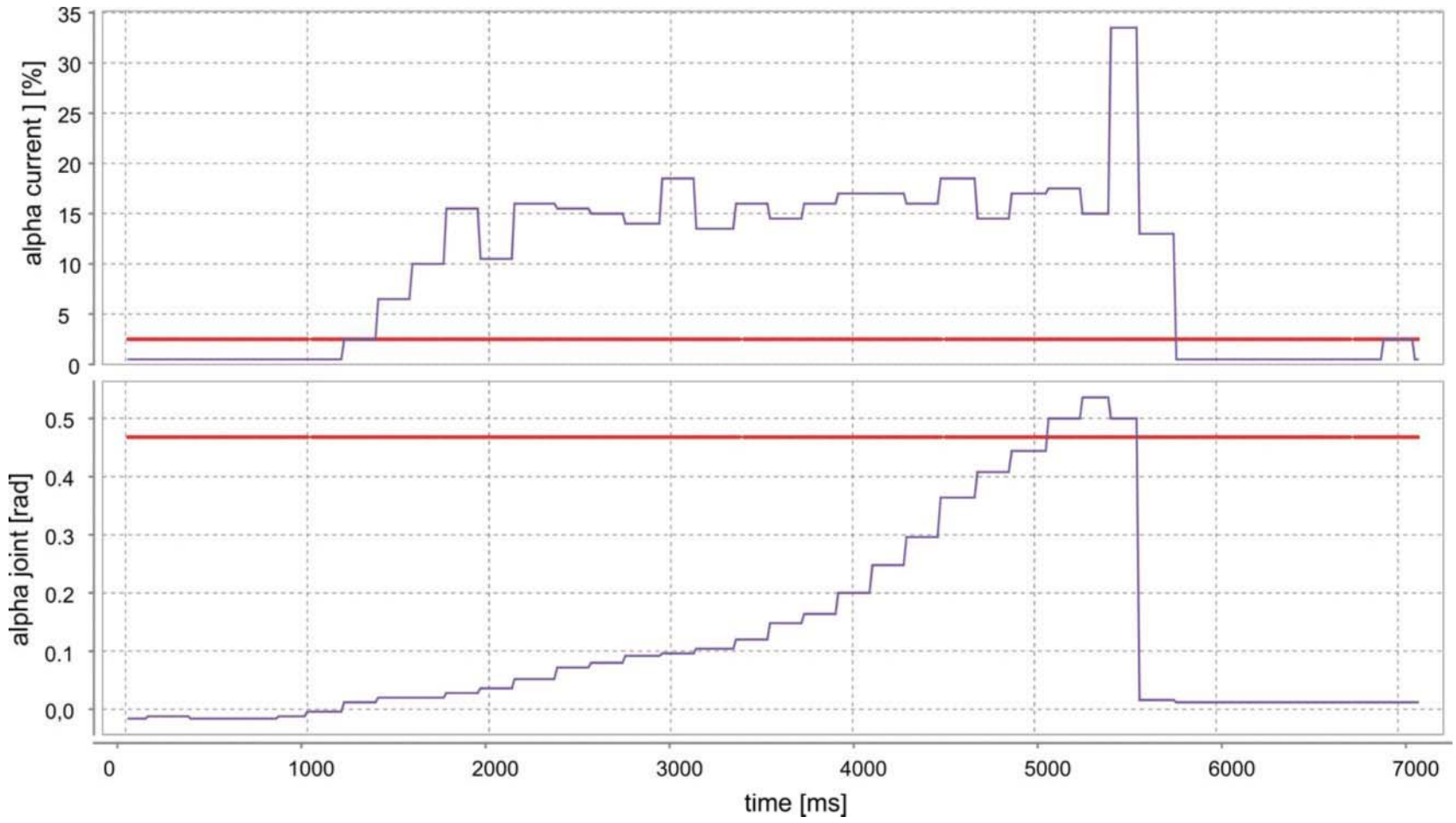
[2]

Emergent Reaction to Externally Acting Forces: Active Complying



[2]

Emergent Reaction to Externally Acting Forces: Step Reflex



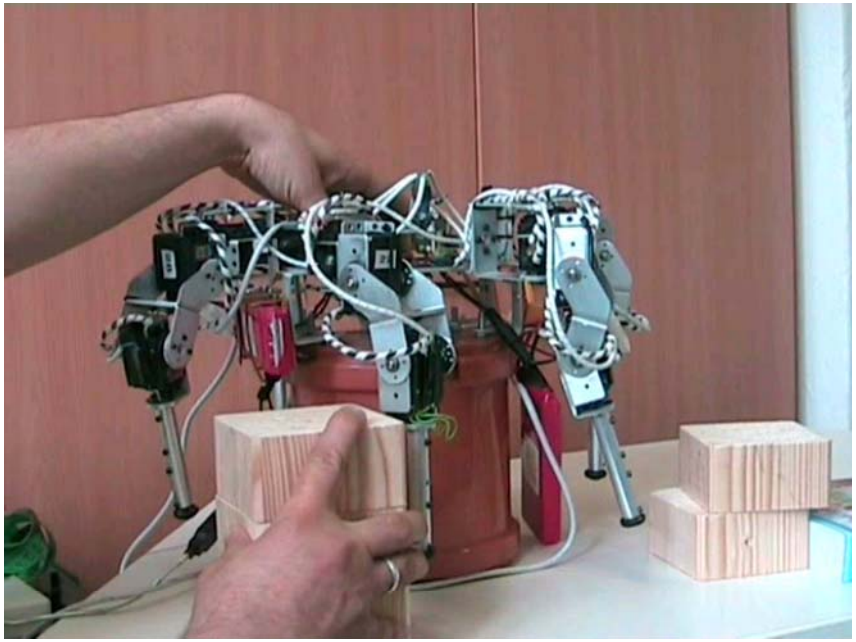
[2]

Emergent Reaction to Externally Acting Forces

[2]

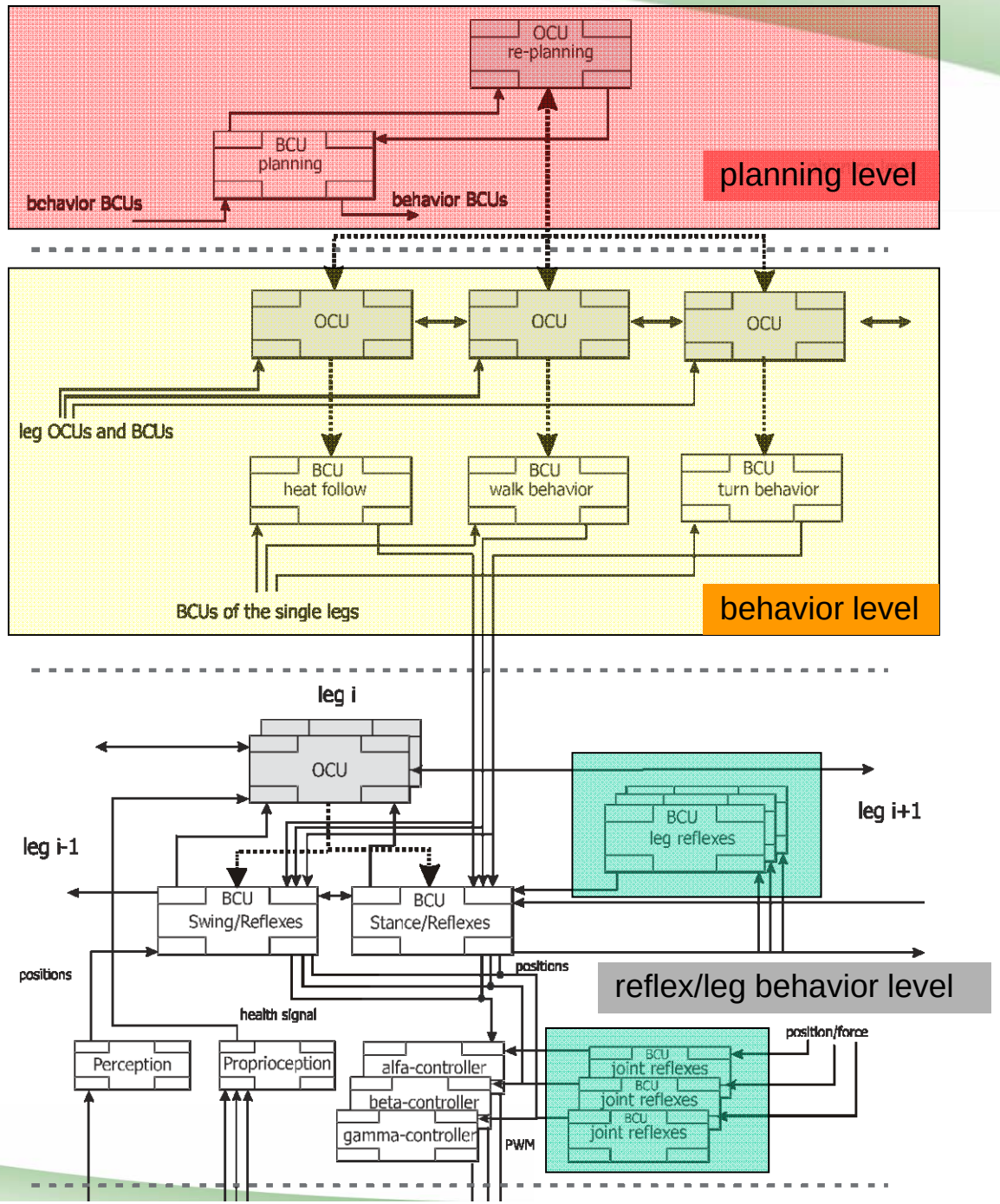
Reflexes

Search reflex

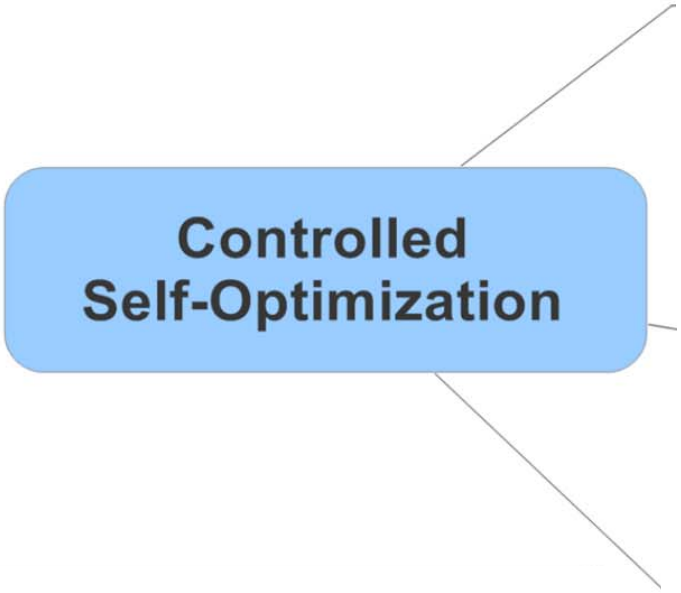


Elevator reflex

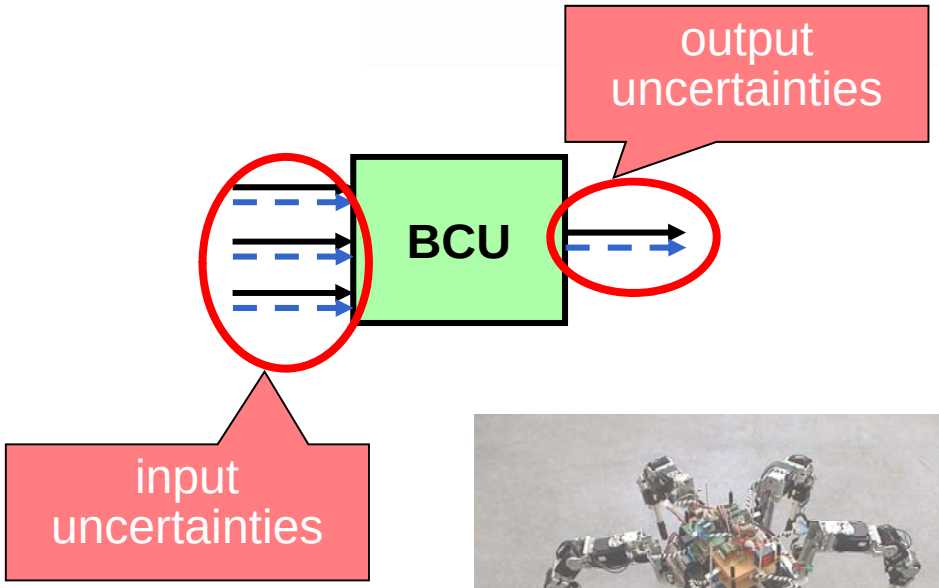
ORCA

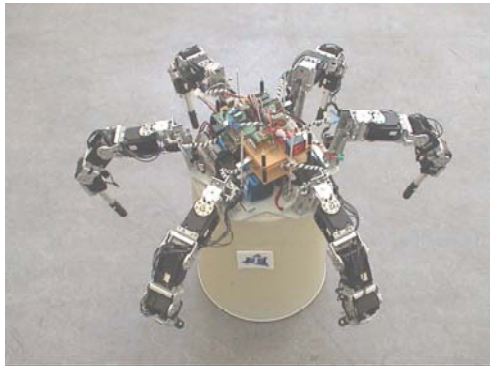

OCU
re-planning
BCU
planning
bchavior BCUs
behavior BCUs
planning level
OCU
OCU
OCU
leg OCUs and BCUs
BCU
heat follow
BCU
walk behavior
BCU
turn behavior
BCUs of the single legs
behavior level
leg i
OCU
leg i-1
BCU
leg reflexes
leg i+1
BCU
Swing/Reflexes
BCU
Stance/Reflexes
positions
positions
reflex/leg behavior level
health signal
position/force
Perception
Proprioception
alfa-controller
beta-controller
gamma-controller
PWM
BCU
joint reflexes
BCU
joint reflexes
BCU
joint reflexes

Methodological Work Package



Adressing Safety Issues





! Output HS not higher than input HS

→ fusion by t-norm operators for non-redundant systems

→ generalization for redundant systems: **Choquet integral**

$$(c)\int_0^1 v(\{s \mid f(s) \geq x\})dx$$

Choquet integral: from theory of multicriterial decision making

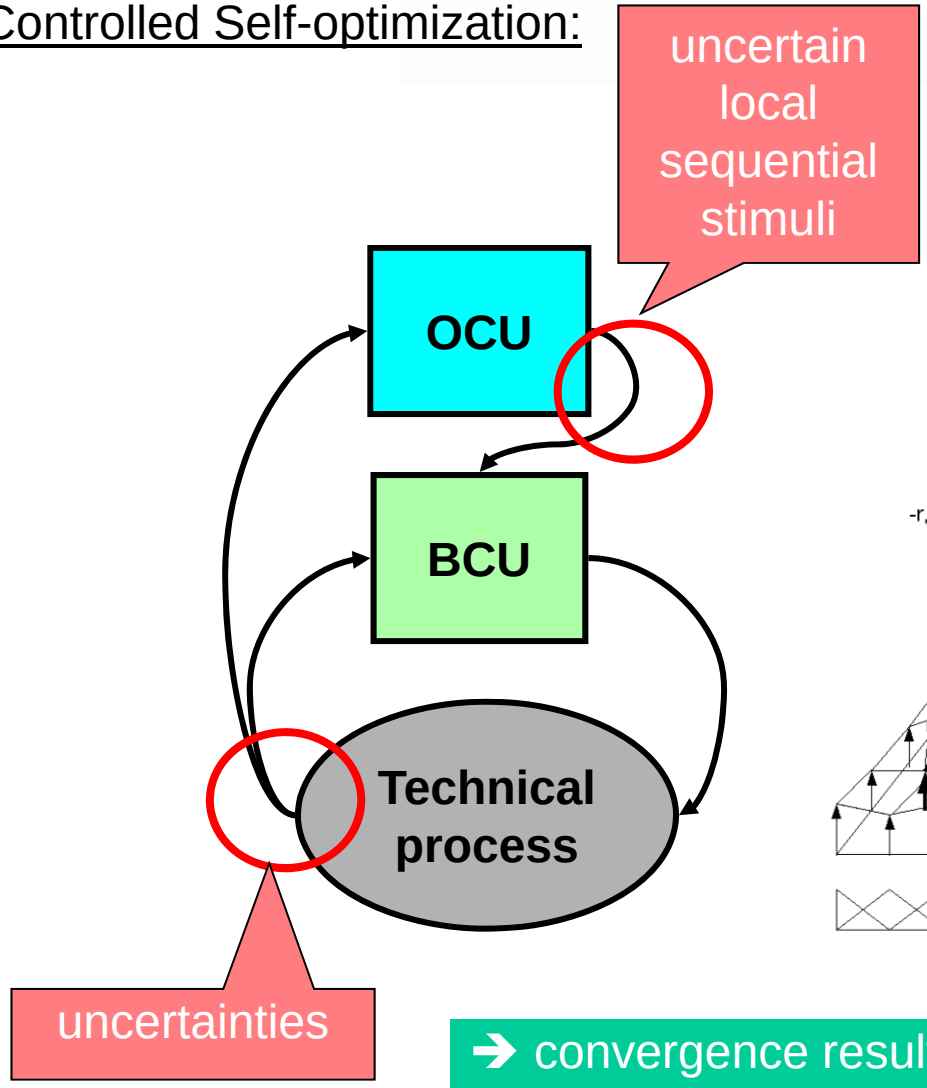
→ consider redundancy

→ consider interaction

S: set of input sources
f: assign HS to input source
F: algebra over *S*
v: assign weight to elements of *F*

Adressing Stability-Plasticity-Issues

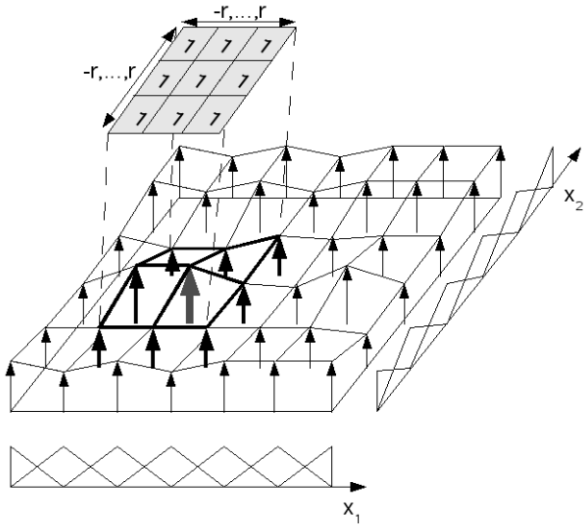
Controlled Self-optimization:



→ ill-posed learning problem

→ **regularization** required

Incremental regularization by the **SILKE approach** (System to Immunize Learning Knowledge-based Elements)



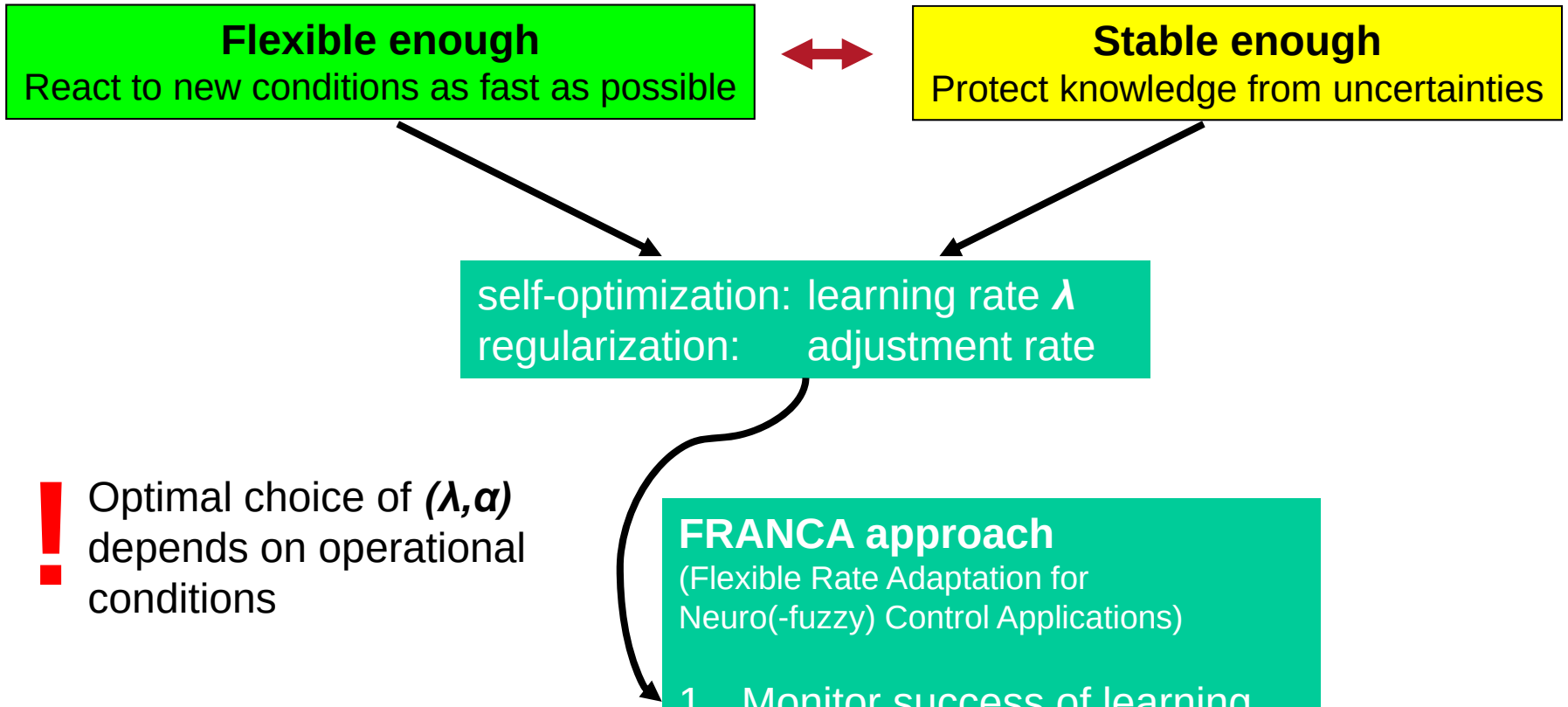
$$|\Delta_{i+1}| = (1-\alpha)\,|\Delta_i|$$

$$|\Delta_{i+1}| \leq |\Delta_i|$$

➔ convergence results: zero-order sTS (self-optimization)

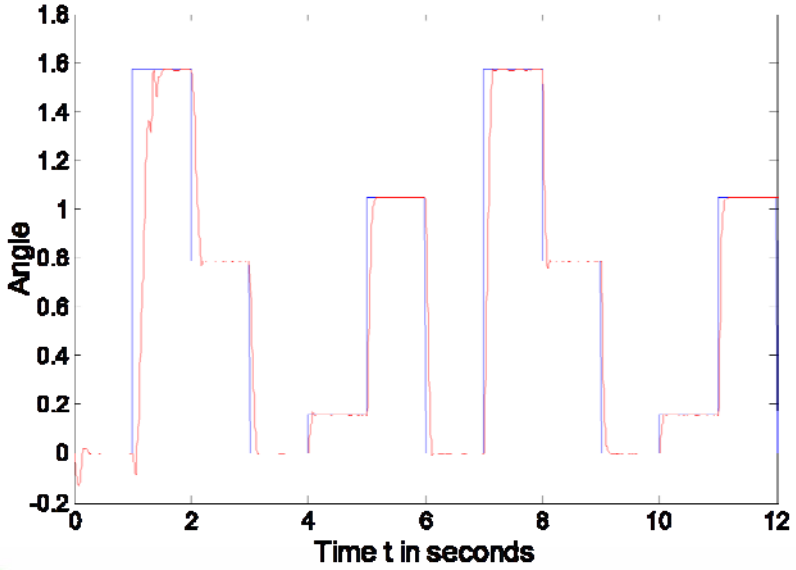
first-order sTS (self-modelling)

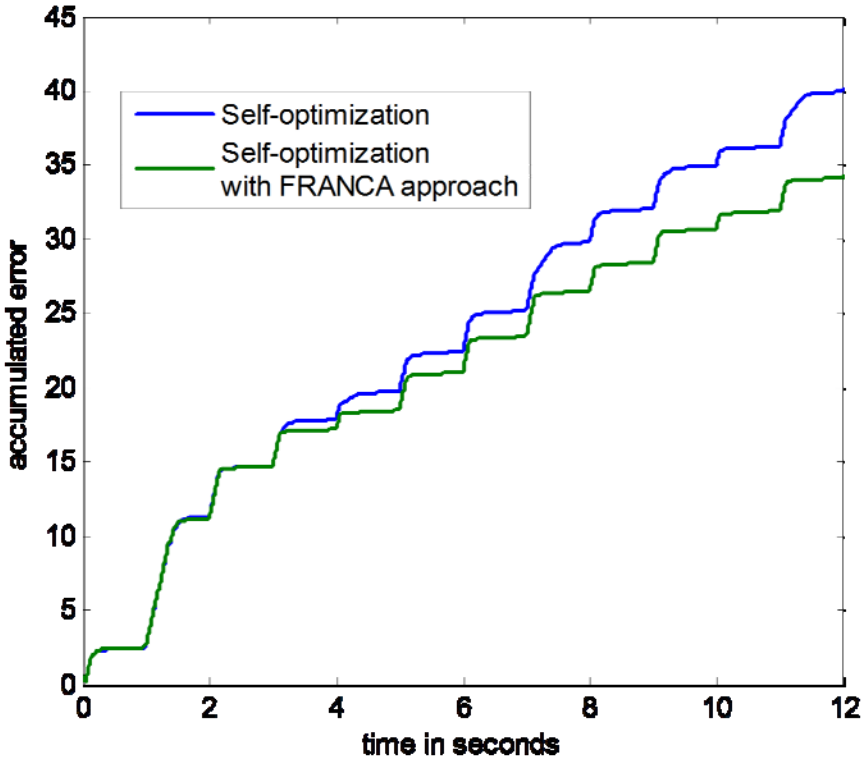
Adressing Stability-Plasticity-Issues



FRANCA approach

Courtesy of Bosch



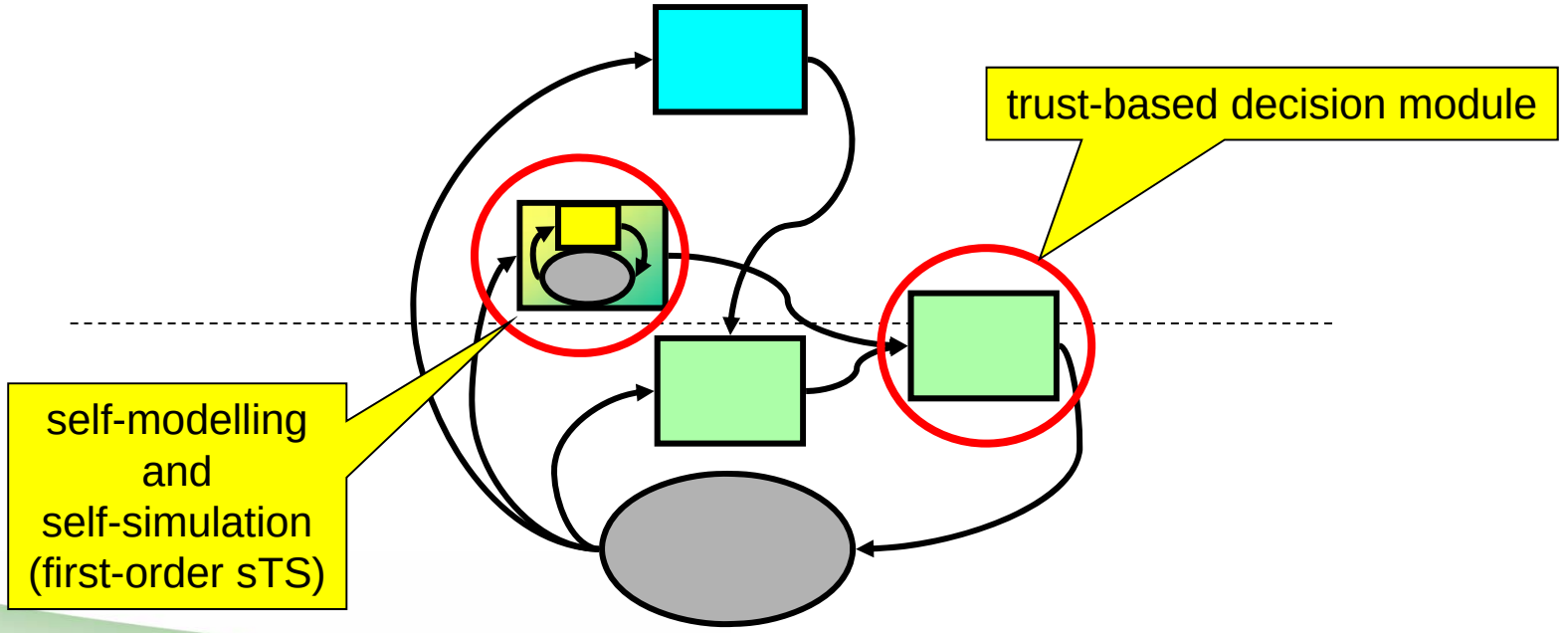


Adressing Exploration-Exploitation-Issues

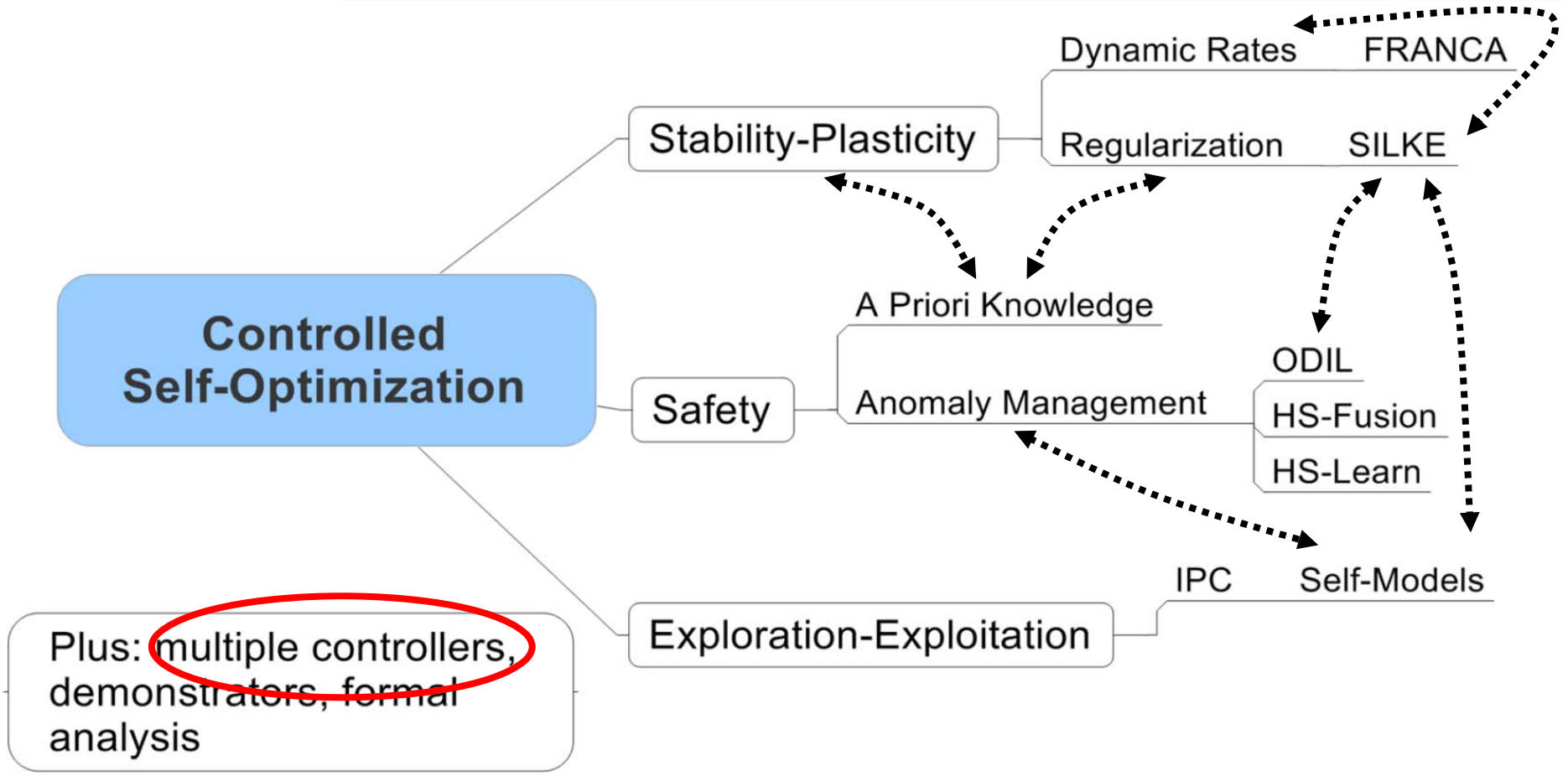
Explore
obtain new, productive learning stimuli
(low performance now, possibly high in future

Exploit
pursuit current goal
(high performance now)

difficult for critical systems, esp. control systems



Methodological Work Package



Outlook

Key issues for third period:

- Integration of a learning methodology into anomaly detection method RADE
- Activation of additional reflexes or deactivating of reflexes done by an OCU to compensate strong anomalies
- Integration of OCU/BCU into OSCAR planning layer, fault tolerant mission planning and replanning
- Regionally specific control of self-optimization by SILKE approach
- Interacting self-optimizing systems
- Self-adaptive reaction to anomalies in BCUs and OCUs

→ Joint demonstration scenario (environmental monitoring)

Recent publications

(1) Jakimovski, B.; Meyer, B.; Maehle, E.: Self-reconfiguring hexapod robot OSCAR using organically inspired approaches and innovative robot leg amputation mechanism. International Conference on Automation, Robotics and Control Systems, ARCS-09, Orlando, USA, July 13-16, 2009

(2) El Sayed Auf, A.; Dudek, N.; Maehle: Hexapod Walking as Emergent Reaction to Externally Acting Forces. Proceedings of Robotica 2009, 67-72, Proccedings Robotica 2009, Portugal 2009

(3) Rosemann, N.; Brockmann, W.; Neumann, B.: Enforcing Local Properties in Online Learning First Order TS-fuzzy Systems by Incremental Regularization. IFSA-EUSFLAT 2009, Lissabon

(4) Rosemann, N.; Brockmann, W.; Lintze, Ch.: Dynamic Rate Adaptationin Self-Adapting Real-Time Control Systems. 32rd Annual Conference on Artificial Intelligence (KI 2009), Workshop Machine Learning for Real-Time Applications, Paderborn

(5) Rosemann, N.; Buschermöhle, A.; Brockmann, W.: Beschleunigung der Selbstoptimierung durch Selbstsimulation. Computational Intelligence Workshop 2009, Bommerholz

(6) Maehle, E.: *Dependability and Fault Tolerance – The Organic Computing Way*. Keynote Talk, 6th Workshop on Dependability and Fault Tolerance. ARCS 09 Workshop Proceedings, 69, VDE-Verlag, Berlin 2009

(7) Grosspietsch, K.-E.; Silayeva, T. A.: *Concepts for the Dependable Operation of Autonomous Robots in Incompletely Known Environments.* Accepted for publication at IDIMT 2009 Conference, Jendrichuv Hradec (Czech Republik), September 2009

(8) Brockmann, W.; Rosemann, N.: *Instantaneous Anomaly Detection in Online Learning Fuzzy Systems*. In: Hoffmann, F.; Cordón, O.; Angelov, P.; Klawonn, F. (eds.): 2008 3rd Int. Workshop on Genetic and Evolving Fuzzy Systems, 23-28, IEEE Press, Piscataway 2008

Recent publications II

(9) A. El Sayed Auf, M. Litza, E. Maehle: *Distributed Fault-Tolerant Robot Control Architecture Based on Organic Computing Principles*. Biologically-Inspired Collaborative Computing, 115-124, Springer-Verlag, Boston 2008

(10) K.-E. Großpietsch, T. A. Silayeva: *Soft Computing Approaches for Achieving Self-Healing Properties in Autonomous Robot.* Proc. IDIMT Conference 2008, Jindrichuv Hradec (Czech Republic), 357-369 Trauner Verlag, Linz 2008

(11) B. Jakimovski, E. Maehle: *Artificial Immune System Based Robot Anomaly Detection Engine for Fault Tolerant Robots*. 5th Int. Conf. on Autonomic and Trusted Computing (ATC-08), LNCS 5060, 177-190, Springer, Berlin 2008

(12) B. Jakimovski, B. Meyer, E. Maehle: *Swarm Intelligence for Self-Reconfiguring Walking Robot*. IEEE Swarm Intelligence Symposium, St. Louis, Missouri, USA, IEEE Press 2008

(13) M. Mladenov, M. Mock, K.-E. Großpietsch: *Fault Monitoring and Correction in a Walking Robot Using LMS Filters.* Proc. 6th Workshop on Intelligent Solutions in Embedded Systems WISES 08, 94-105, Regensburg 2008

(14) N. Rosemann, J. Hülsmann, W. Brockmann: *Disrupted Learning - Lernen bei harten Zustands- oder Strukturwechseln*. 18. Workshop „Computational Intelligence“, In: Proc. 18. Workshop Computational Intelligence 2008, 105-117, Universitätsverlag Karlsruhe 2008

(15) N. Rosemann, B. Neumann, W. Brockmann: *Formale Eigenschaften des SILKE_Ansatzes zur Kontrolle selbstoptimierender Systeme*. In: Hegering, H.-G.; Lehmann, A.; Ohlbach, H.J.; Scheideler, C. (Hrsg.): Proc. Informatik 2008 Beherrschbare Systeme - dank Informatik, LNI, 755-762, Gesellschaft für Informatik, Bonn 2008

Student's Theses

1. N. Dudek: *Adaptive reflexbasierte Kraftverteilung eines hexapoden Roboters*. Bachelor Thesis, Institute of Computer Engineering, University of Lübeck, December 2008
2. J. Hartmann.: *Health Signal Generierung und Monitoring einer sechsbeinigen Laufmaschine*. Bachelor Thesis, Institute of Computer Engineering, University of Lübeck, October 2008
3. O. Polat*: Methoden zum Health Monitoring bezüglich komplexer Anomalien bei Robotik-Systemen.* Diplomarbeit, Rheinische Fachhochschule Köln 2008
4. F. Sennoune: Soft *Computing und Fehlerdiagnose bei mechatronischen Systemen.* Diplomarbeit, Rheinische Fachhochschule Köln 2008
5. B. Neumann: *Formale Eigenschaften des SILKE-Ansatzes beim Online-Lernen in adaptiven Fuzzy-Systemen*. Diplomarbeit, University of Osnabrück 2008
6. H.-T. Reimers: *Entwicklung und Anwendungskonzept einer Spezialhardware für die Ansteuerung kinematischer Servoketten*. Master Thesis, University of Osnabrück 2008
7. Th. Escher: *Modellierung und Inbetriebnahme einer mobilen Pendelplattform*. Bachelor Thesis, University of Osnabrück 2009
8. A. Martel: *Comparison of Safe Learning Controllers for a Pneumatic Actuator*. Bachelor Thesis, University of Osnabrück 2009
9. A. Buschermöhle: *Online-Optimierung in technischen Systemen durch Selbstsimulation*. Master thesis, University of Osnabrück
10. B. Kloster: *Online-Generierung von interpretierbaren Selbstmodellen*. Master thesis, University of Osnabrück

Miscellaneous

- Patent

  B. Jakimovski: *Robot Leg Amputation Mechanism R-LEGAM*. Patentanmeldung PVA/8065, Patent-und Verwertungsagentur Schleswig-Holstein 2008

- Best Student Paper Award

  [2] A. El Sayed Auf, N. Dudek,. E. Maehle: *Hexapod Walking as Emergent Reaction to Externally Acting Forces*. ROBOTICA 2009, 67-72, Castelo Branco, Portugal 2009

Outlook

Key issues for third period:

- Integration of a learning methodology into anomaly detection method RADE
- Activation of additional reflexes or deactivating of reflexes done by an OCU to compensate strong anomalies
- Integration of OCU/BCU into OSCAR planning layer, fault tolerant mission planning and replanning
- Regionally specific control of self-optimization by SILKE approach
- Interacting self-optimizing systems
- Self-adaptive reaction to anomalies in BCUs and OCUs

→ Joint demonstration scenario (environmental monitoring)