Organic Fault-tolerant Robot Control Architecture

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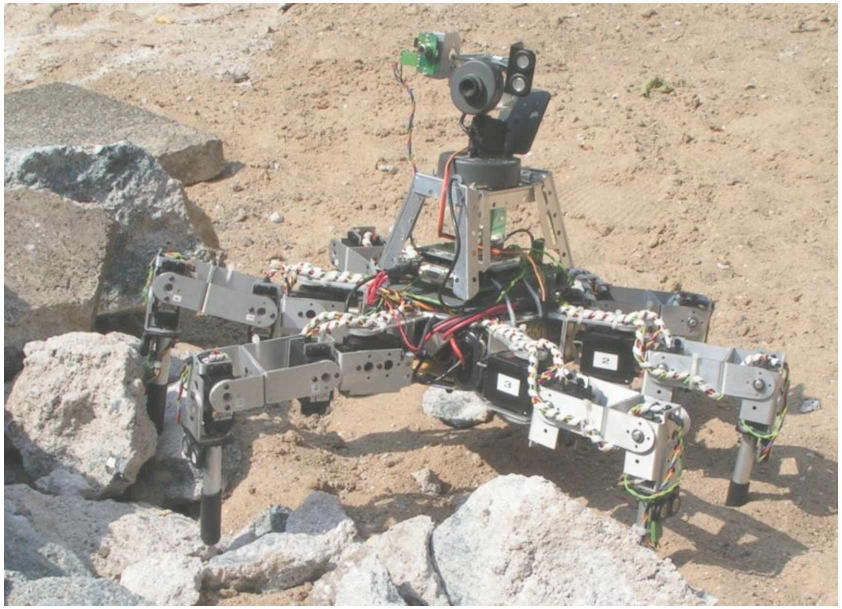
Motivation

Autonomous mobile robots in human environments

unstructured, dynamically changing environment

no explicit model of the environment

-> fault-tolerance, safety

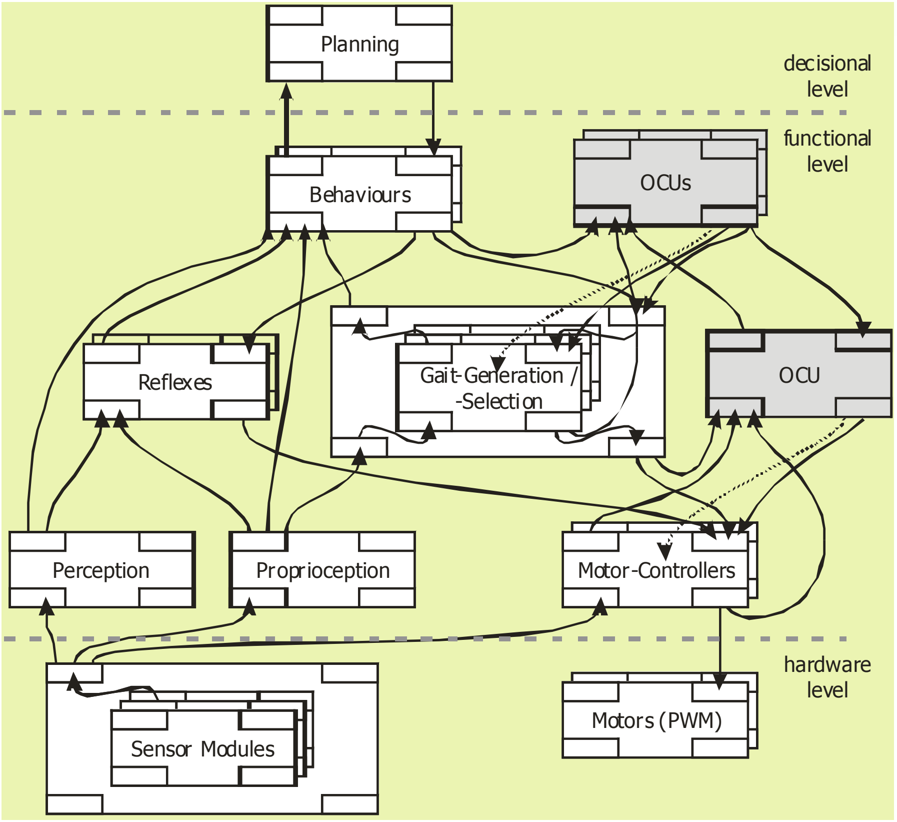


complex control systems

no explicit fault model

-> engineering bottleneck

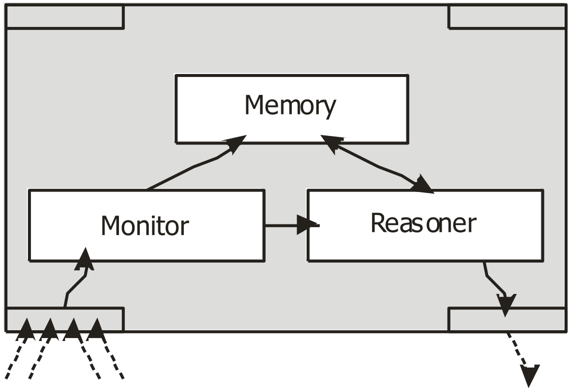
ORCA – Organic Robot Control Architecture



BCU = Basic Control Unit

OCU = Organic Control Unit

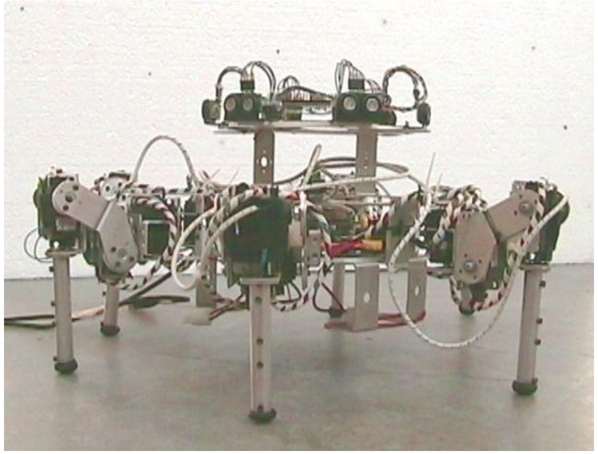
OCU-Architecture

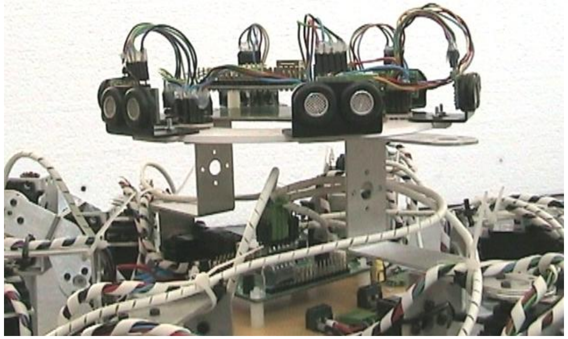


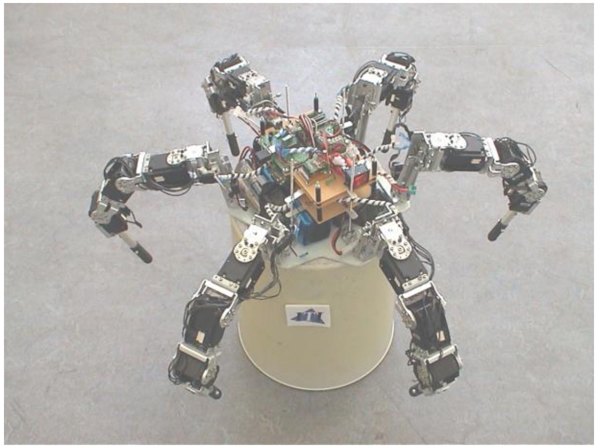
- Monitor: anomaly detection
- Memory: short term history (learning)
- Reasoner: hard real-time determination of a counteraction

Variant of Observer/Controller Architecture

Platform: six-legged walking machine OSCAR



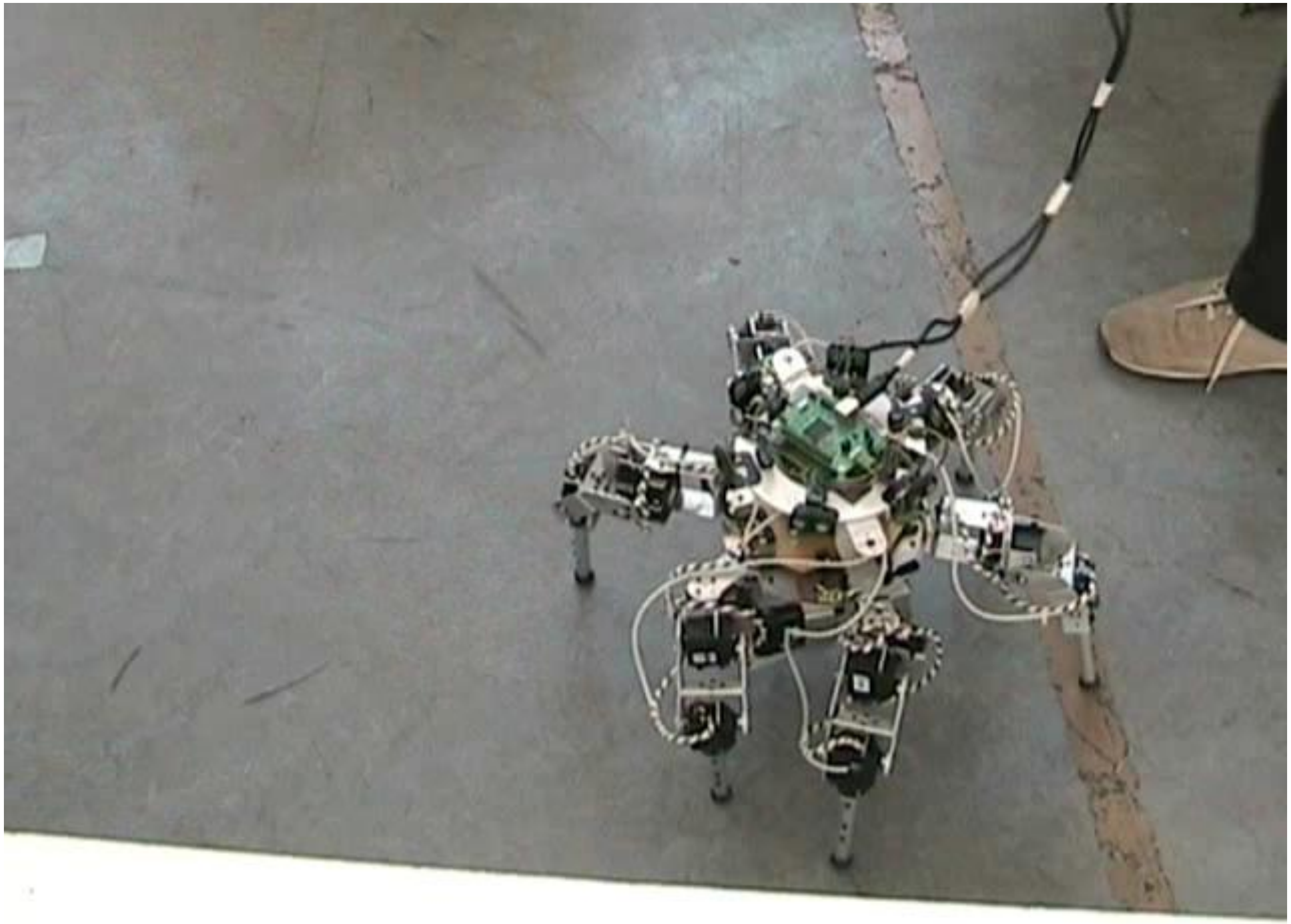




New Features:

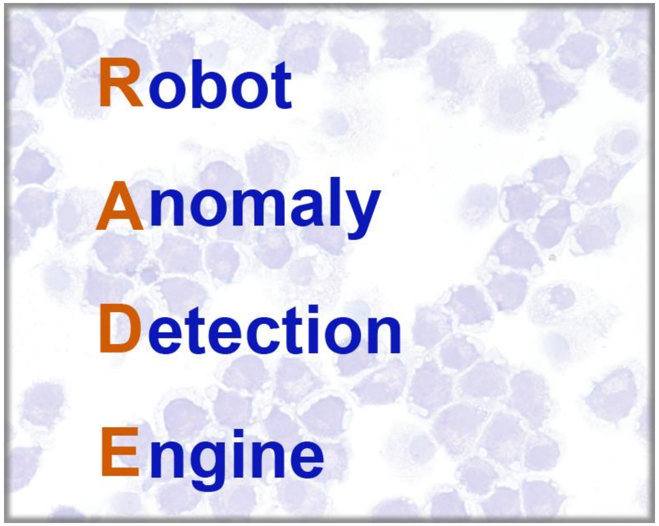
- Digital, stronger servos
- Feedback of internal servo states
- Enhanced lifting capacity
- Ultrasonic sensor ring
- Leg-(de)attachment
- More computational power

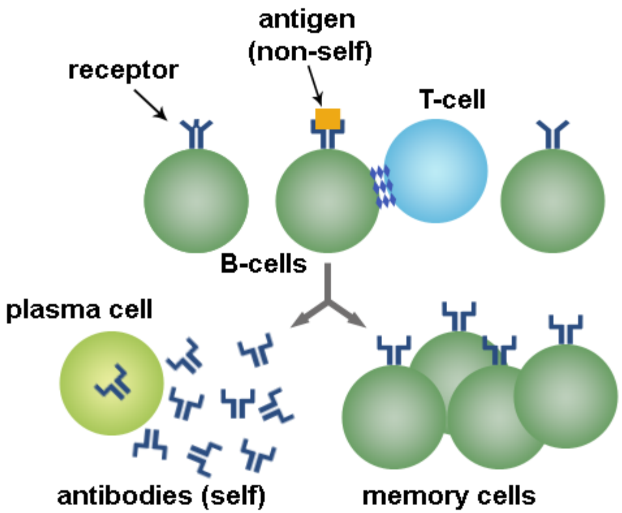
High-level, sensor-based behavior



R.A.D.E.
Robot Anomaly Detection Engine

- Artificial immune system based anomaly detection method for fault tolerant robots





- Based on self-nonself discrimination and clonal selection principles found within the natural immune system

- Already presented information theoretical approach for anomaly detection is also in further development

[1,2]

R.A.D.E.
Robot **A**nomaly **D**etection **E**ngine

- Implementation example:

Situation

Behavior: Walking
Current: Very_High

NON-SELF SET

IF		THEN		WEIGHT	
IF	Behavior is Walking AND Current is Very_High	THEN	Anomaly is PRESENT	0.3	↑
IF	Behavior is Walking AND Current is High	THEN	Anomaly is PRESENT	0.5	
IF	...	THEN	Anomaly is PRESENT	...	

SELF SET

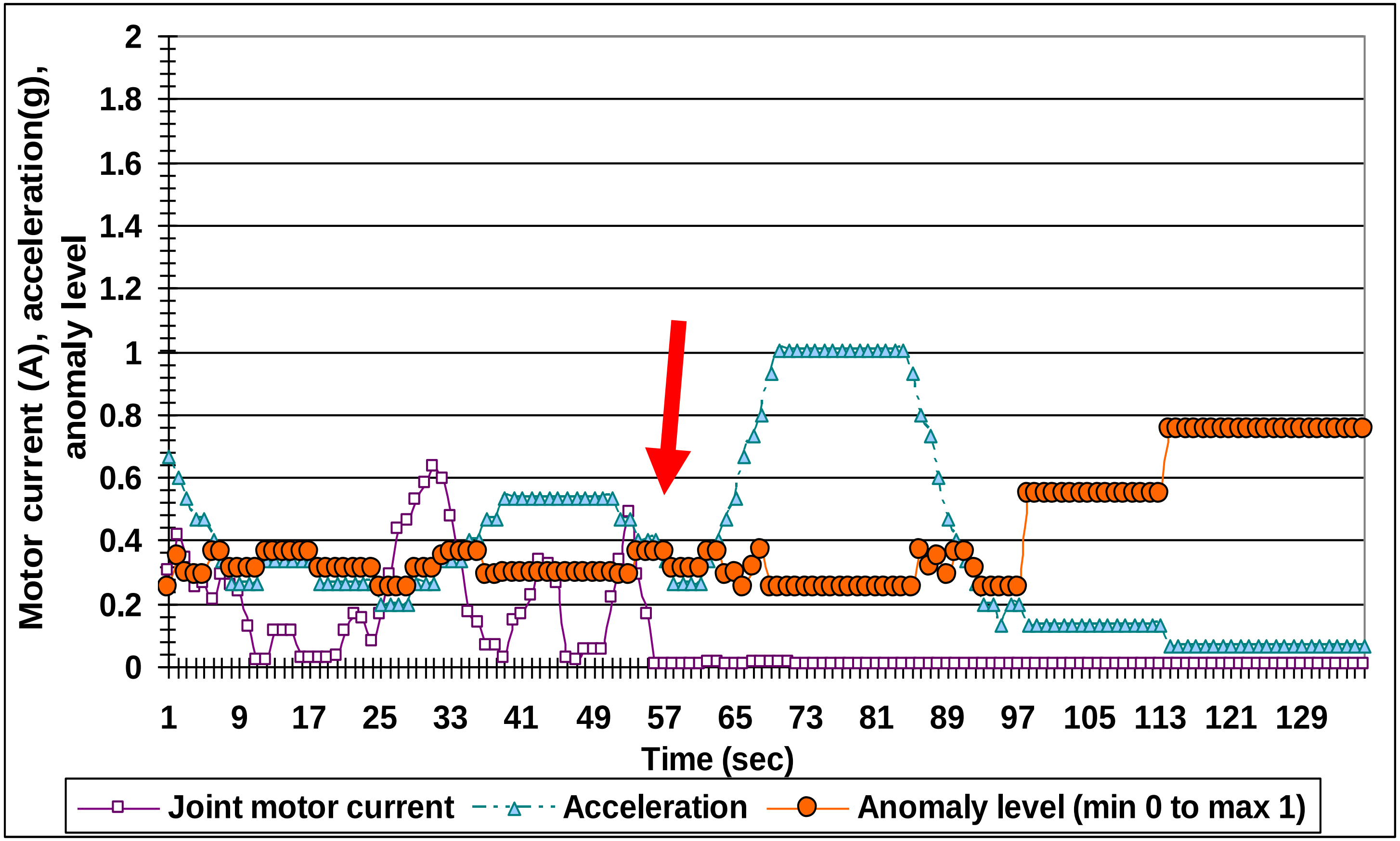
IF		THEN		WEIGHT	
IF	Behavior is Walking AND Current is Medium	THEN	Anomaly is ABSENT	0.4	↓
IF	Behavior is Walking AND Current is Small	THEN	Anomaly is ABSENT	0.6	↓
IF	...	THEN	Anomaly is ABSENT	...	↓

[1,2]

R.A.D.E.
Robot Anomaly Detection Engine

Experiment – Anomaly detection

without RADE dynamics



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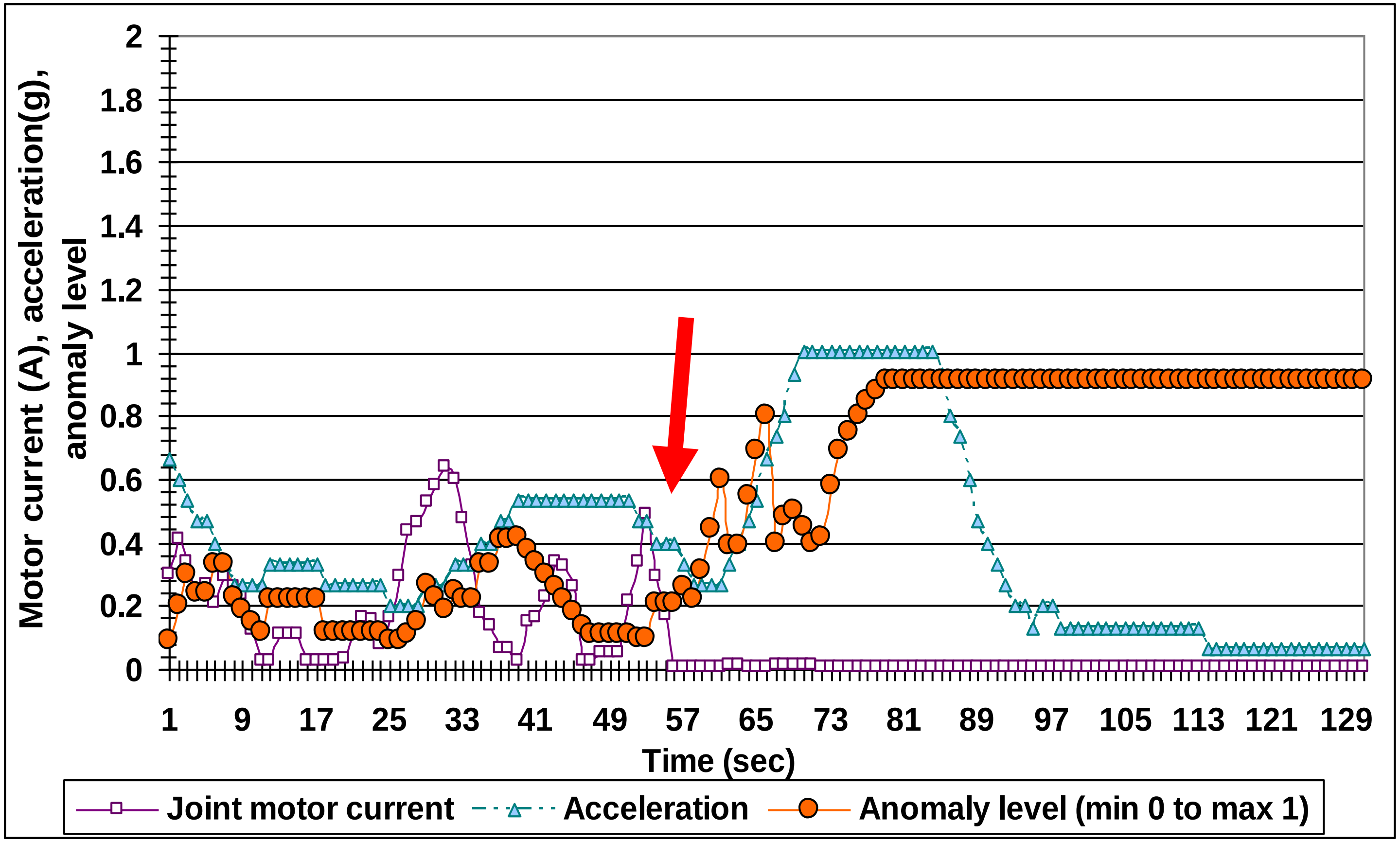
R.A.D.E.
Robot Anomaly Detection Engine

Experiment – Anomaly detection

with RADE dynamics

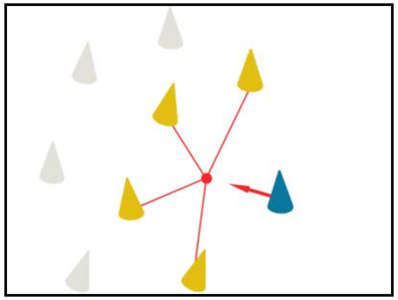


[1,2]

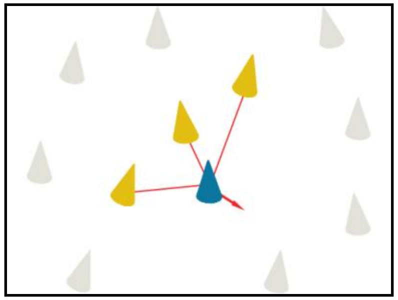
S.I.R.R.
Swarm **I**ntelligence for **R**obot **R**econfiguration

- Swarm Intelligence based method for robot reconfiguration.
  Used to reconfigure the spatial posture of the robot’s legs, after some failure has occurred within them.

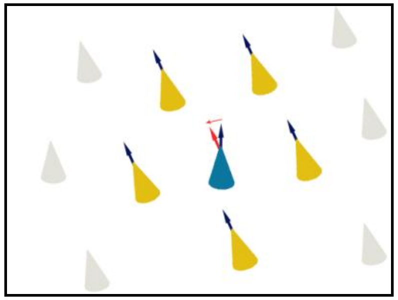
Based on the intrinsic properties seen within swarms and boids in nature.



cohesion



separation

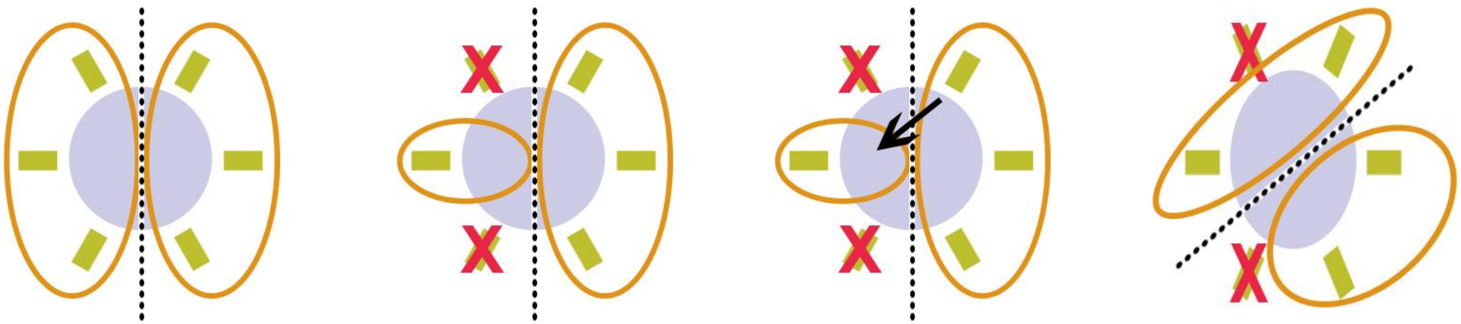


alignment

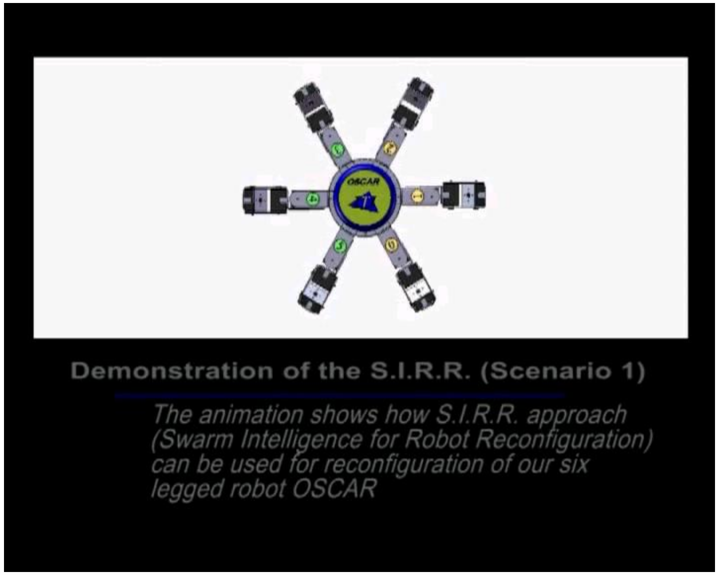
[1,3]

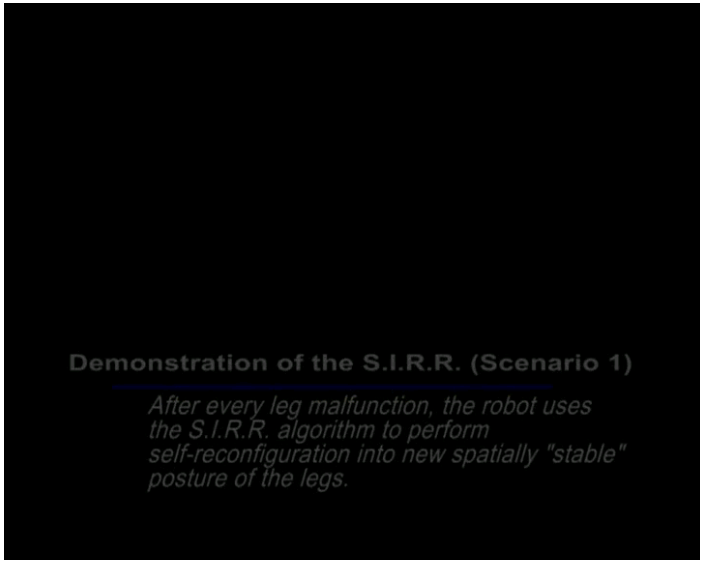
S.I.R.R.
Swarm **I**ntelligence for **R**obot **R**econfiguration

- Example of robot reconfiguration using S.I.R.R. - Schematic view



- Experimental test-case reconfiguration on robot OSCAR





[1,3] Reconfiguration scenario – legs 0, 2, 3, 4 get malfunctioned

Self-optimization by learning

- Design issues of learning
  - Learning strategy (→directed self-learning)
  - Learning architecture (→ORCA architecture)
  - Safe learning (→controlled self-optimization)
- Interplay of learning and faults
  - Detect faults by learning (→diagnostic adaptive filters)
  - Compensate faults by learning (→corrective adaptive filters)
  - Detect faults of learning itself (→ODIL approach)
  - Compensate faults of learning itself (→SILKE approach)
- Learning at different architectural levels
  - Signal level (→adaptive filters)
  - Functional level (→sTS fuzzy systems)
  - Module level (→ELISE approach)

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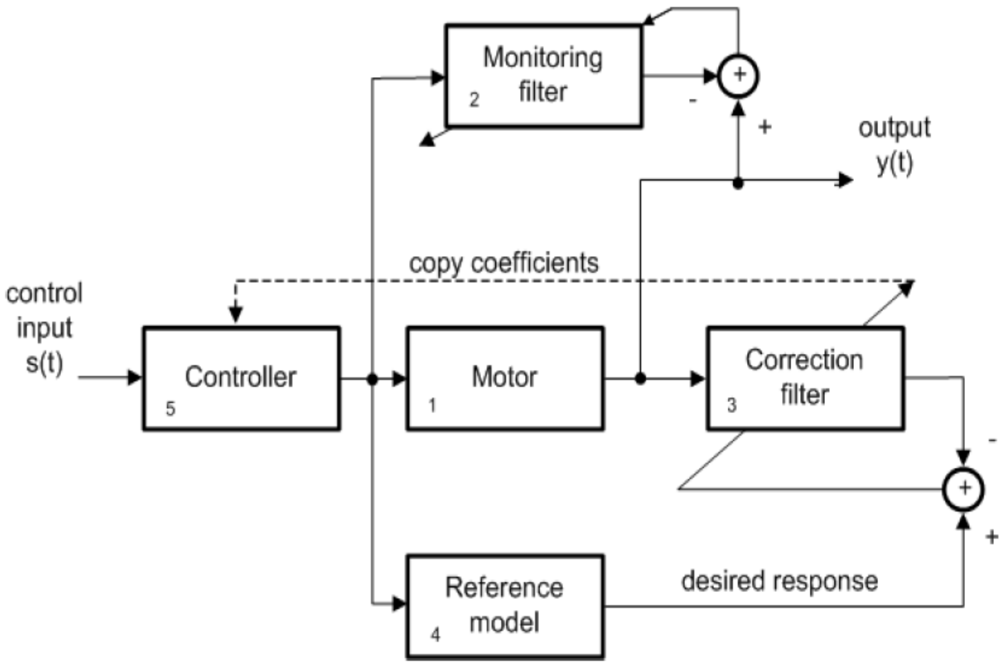
  - Module level (→**ELISE approach**)

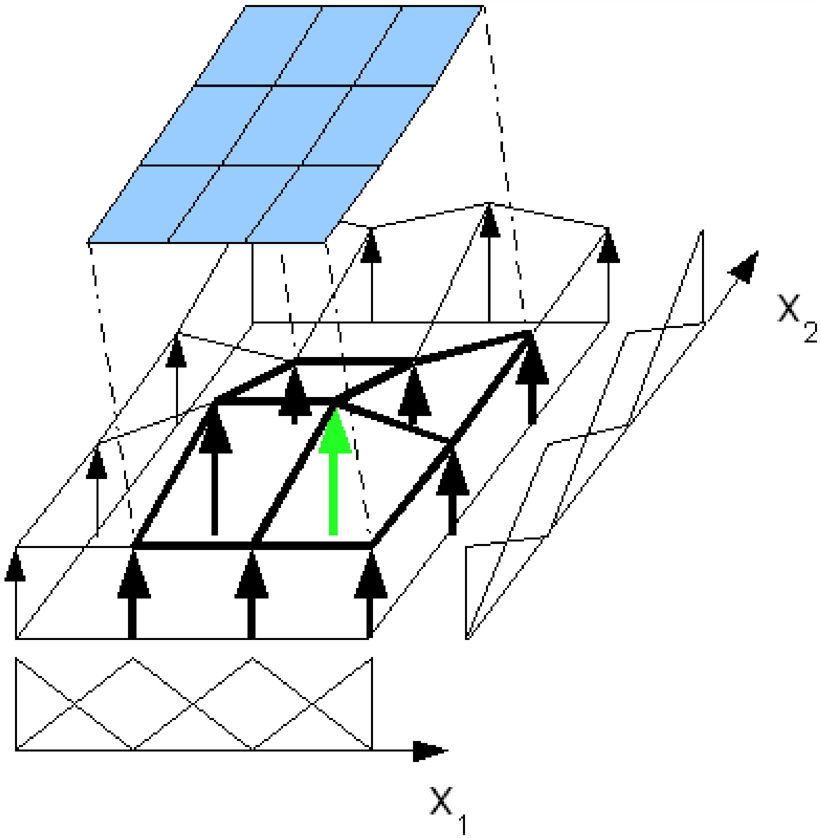
Adaptive Filters for Diagnosis

- Train filter online to represent dynamic behavior of the system
- Classification by identifying patterns in the learnt filter coefficients
- Cooperation of diagnosis and local compensation to signal uncorrectable faults to higher levels
- Investigations on OSCAR kinematics



[4,5]

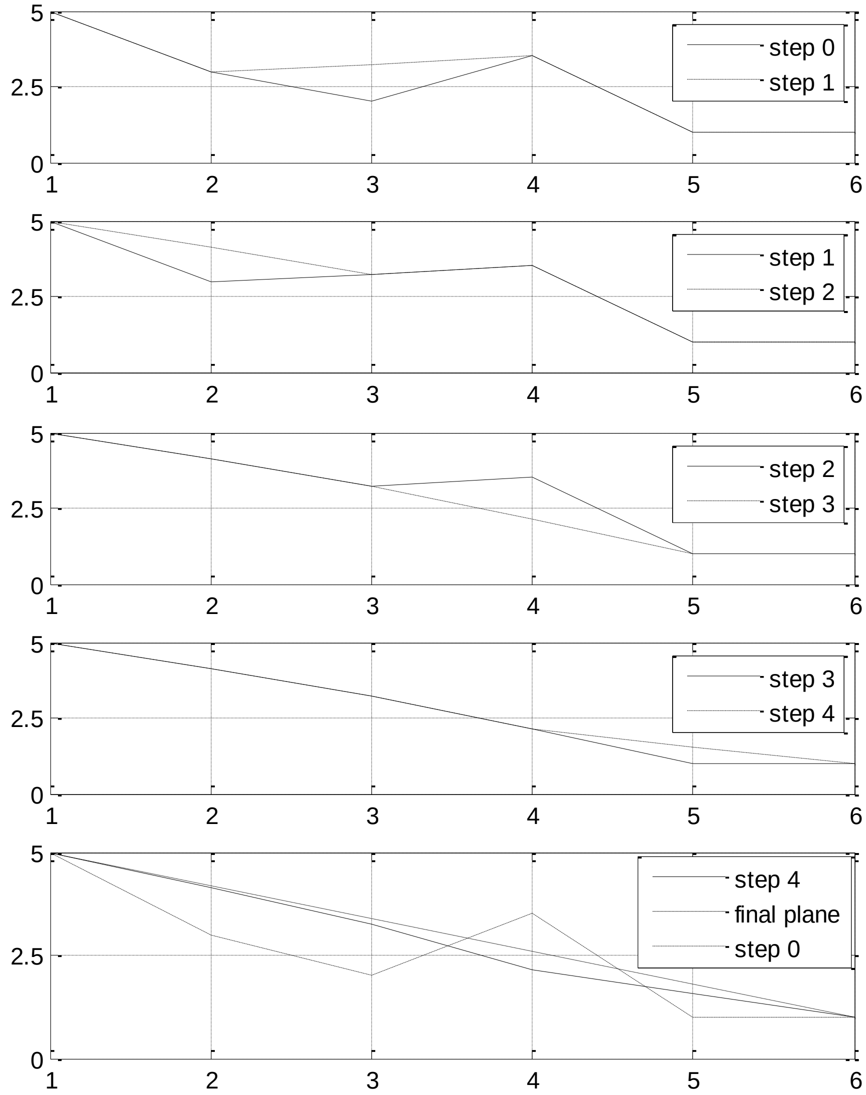
SILKE approach



- Self-optimization by function approximation
- Idea: control the self-optimizing process to handle:
  - Chaotic feedback loop
  - Stability-plasticity-dilemma
- Reflect and control meta-level properties of underlying system
- Efficient for special Takagi-Sugeno fuzzy systems

SILKE approach

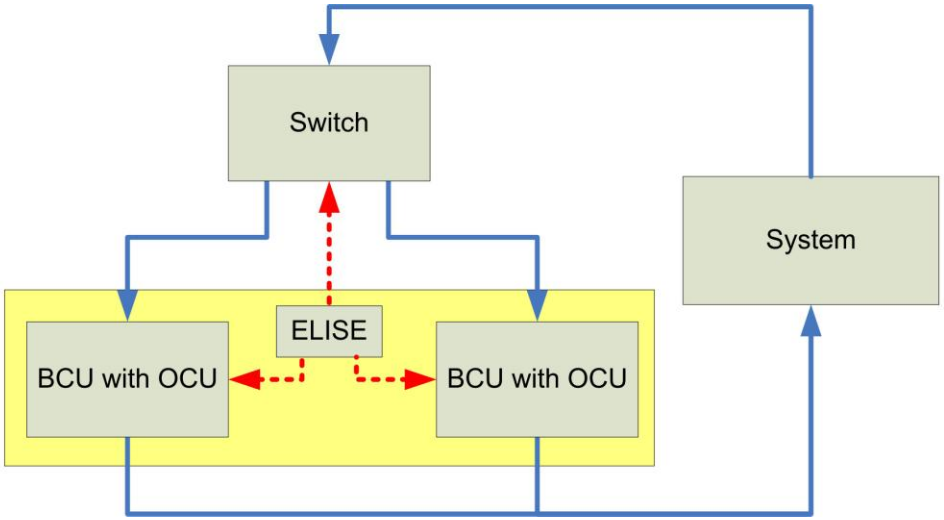
- So far: demonstration on real systems
- New: formalization and proof of system properties
- Current results: proof that SILKE approach with averaging template guides learning towards higher local linearity



[7]

Problem: Interrupted Learning

- Situation: Multiple selfopt. systems work in turn
- Learning is problematic in switching regions of input space, only sparse learning inputs
- May cause individual learning systems to converge too slowly or even to converge not at all



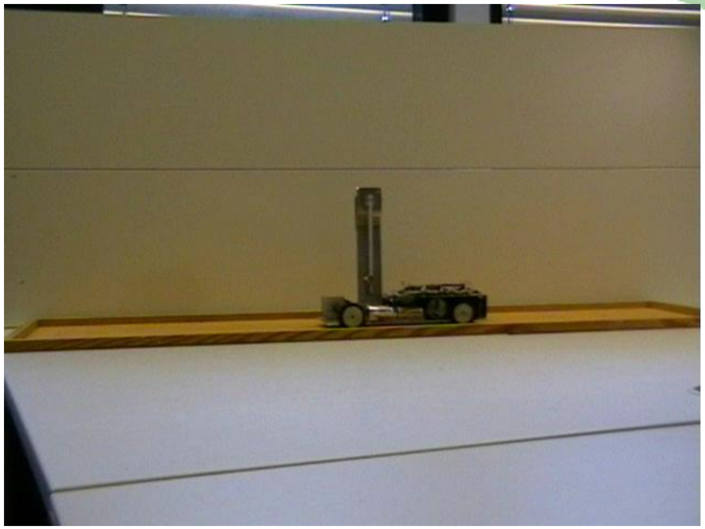
- Aim: Exploit learning stimuli in the switching regions as effective as possible

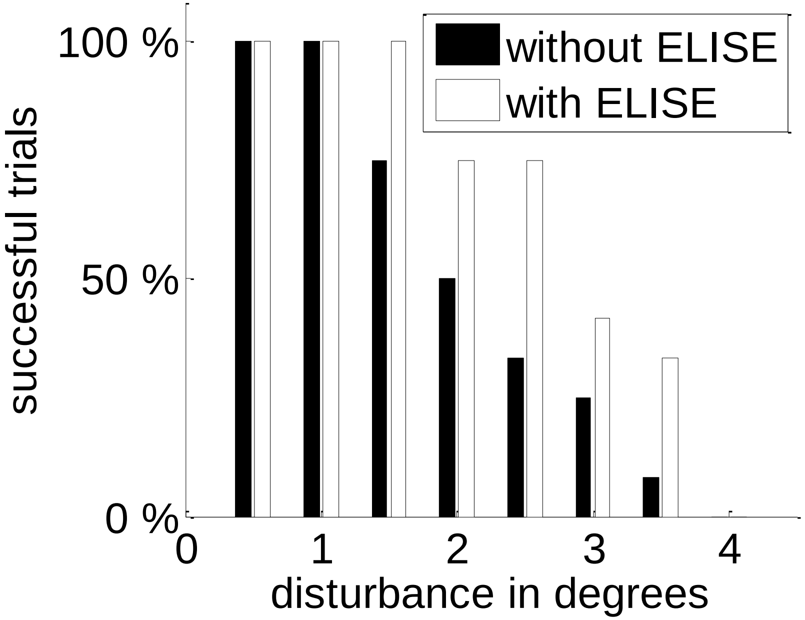
ELISE approach
(Exploiting Learning stimuli in Interrupted SElf-optimization)

- Allow learning to continue after switching between BCUs
- Generate additional learning stimuli after unsuccessful switchings
- Adapt switching criteria to speed up convergence

→ Speed up convergence
→ Improved system robustness

[8]





Summary

- Current work:
  - Anomaly detection
  - Self-healing & reconfiguration
    - On signal level
    - On leg level
  - Controlled self-optimization
    - Formal analysis
    - ELISE approach

- Future work until summer 2009:
  - Incorporation of learning into robot OCUs
  - Learning in unhealthy system states
  - Self-organizing high-level behaviors and reflexes

References

[1] www.iti.uni-luebeck.de/index.php?id=oscar&L=1

[2] Jakimovski, B.; Maehle, E. : *Artificial Immune System Based Robot Anomaly Detection Engine for Fault Tolerant Robots*. 5th International Conference on Autonomic and Trusted Computing (ATC-08), Oslo, Norway, 2008, 177-190, Springer Berlin / Heidelberg, 2008

[3] Jakimovski, B.; Meyer, B.; Maehle, E. : *Swarm Intelligence for Self-Reconfiguring Walking Robot*,, IEEE Swarm Intelligence Symposium, St. Louis, USA, September 21-23, 2008 [to appear].

[4] Mladenov, M.; Mock, M.; Großpietsch, K.-E.: *Fault Monitoring and Correction in a Walking Robot Using LMS Filters*. Proceedings of the Sixth Workshop on Intelligent Solutions in Embedded Systems WISES 08, Regensburg 2008

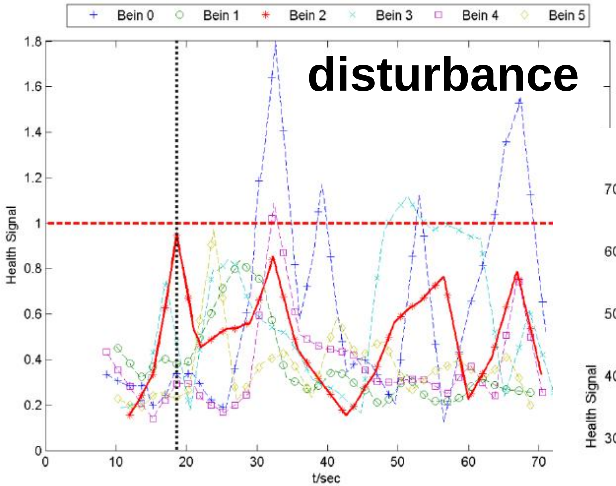
[5] Großpietsch, K.-E.; Silayeva, T.A.: *Soft Computing Approaches for Achieving Self-Healing Properties in Autonomous Robots*. Proc. IDIMT 2008 Conf., Jindrichuv Hradec (Czech Republik), Sept.10-12, 2008

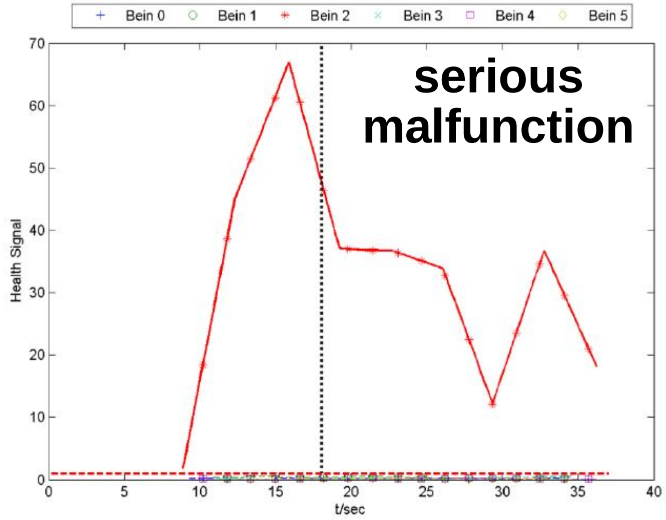
[6] Hartmann, J.: *Health Signal Generierung und Monitoring einer sechsbeinigen Laufmaschine.* Studienarbeit: Institut für technische Informatik, Universität zu Lübeck, 2008

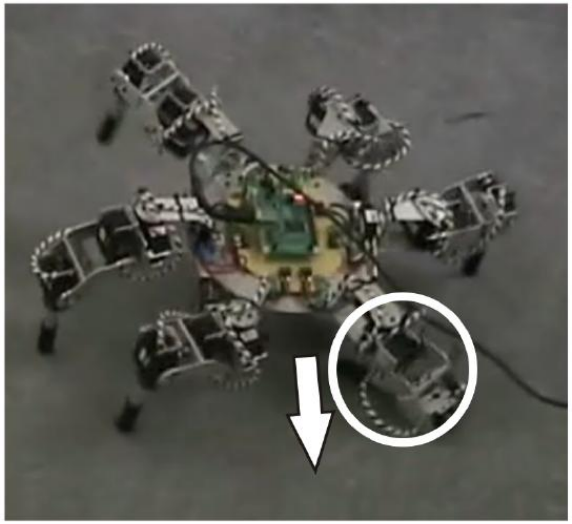
[7] Rosemann, N.; Neumann, B.; Brockmann, W.: *Formale Eigenschaften des SILKE-Ansatzes zur Kontroller selbstoptimierender Systeme*. GI Jahrestagung, Workshop Organische und Adaptive Systeme, München, 2008

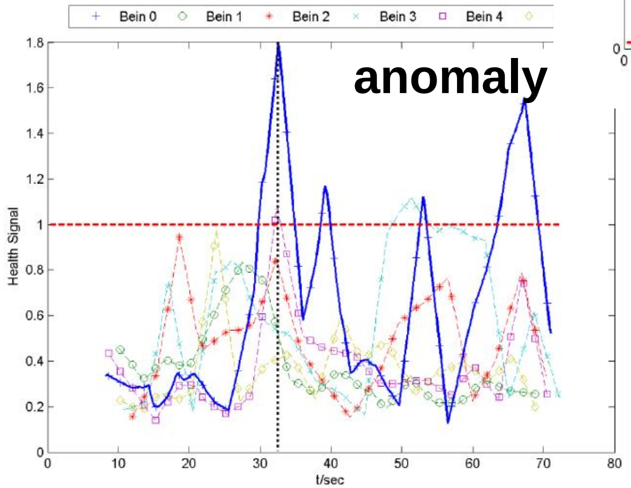
[8] Rosemann, N.; Hülsmann, J.; Brockmann, W.: *Disrupted Learning – Lernen bei harten Zustands- order Strukturwechseln*. Computational Intelligence Workshop, Bommerholz, 2008

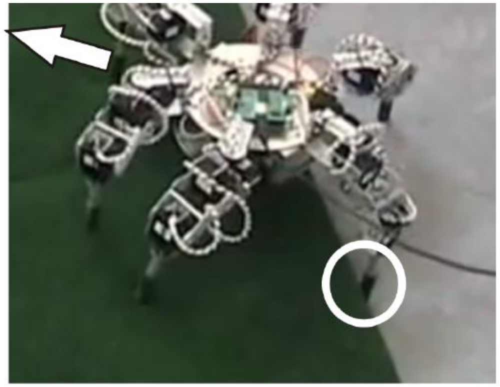
Detection of different anomalies using hierarchical Leg-Health-Signals











Hierarchical structure of HS allows:

- source detection
- classification

[8]

- Snapshots of dynamics of R.A.D.E. anomaly detection surface