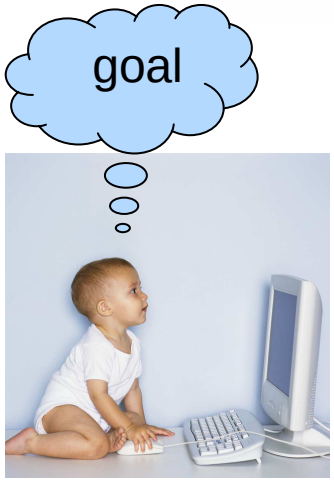
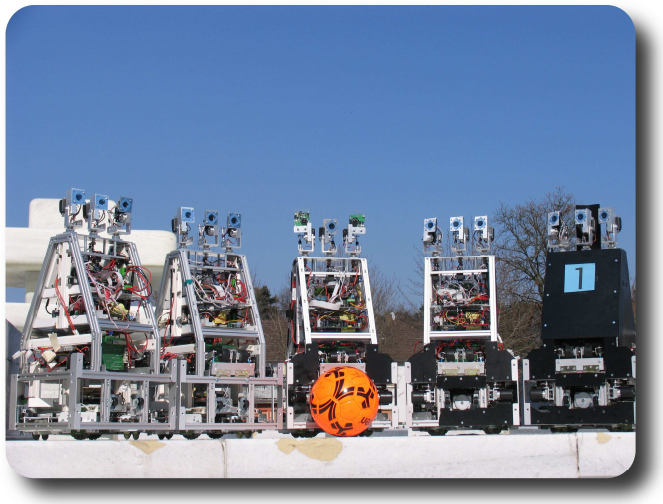
Organic Computing Status Colloquium / Zurich / Sept 2008





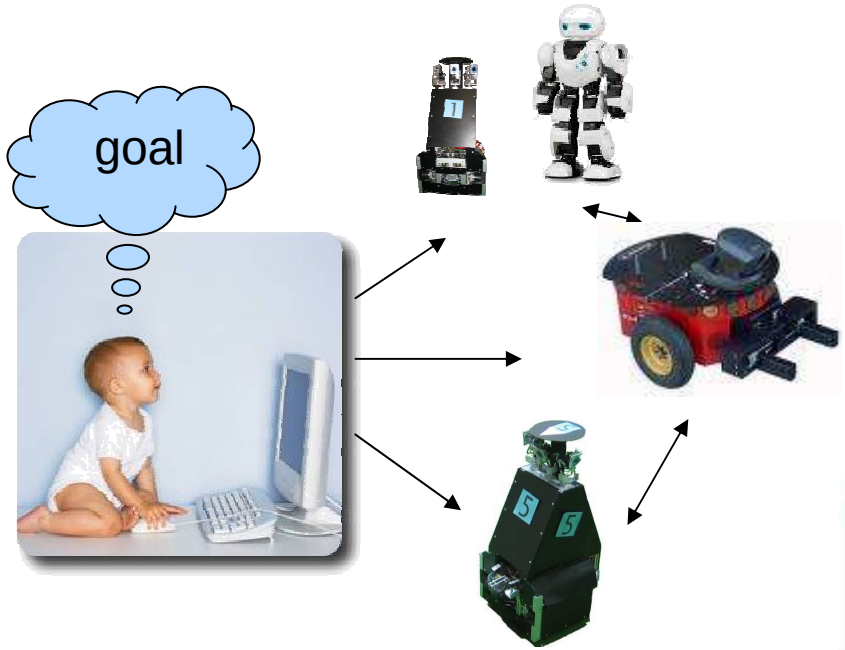
Evolving Societies of Learning Autonomous Systems

(ESLAS)

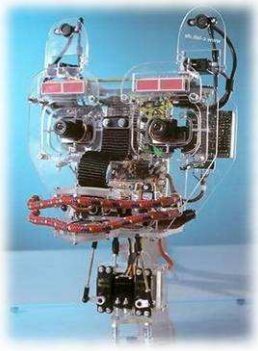
Franz Rammig, Bernd Kleinjohann, Willi Richert
University of Paderborn (richert@c-lab.de)

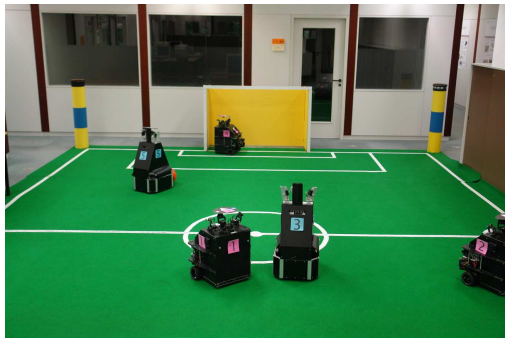
The ESLAS project

- **Goal:** Self-organization of individual learning robots in groups



- **How to achieve a specified goal?**
  → self-exploration, individual learning
- **How to speed up exploration and converge to group behavior?**
  → imitation
- **How to control emergent behavior?**
  → decentralized evaluation functions inspired by socio-biologically principles



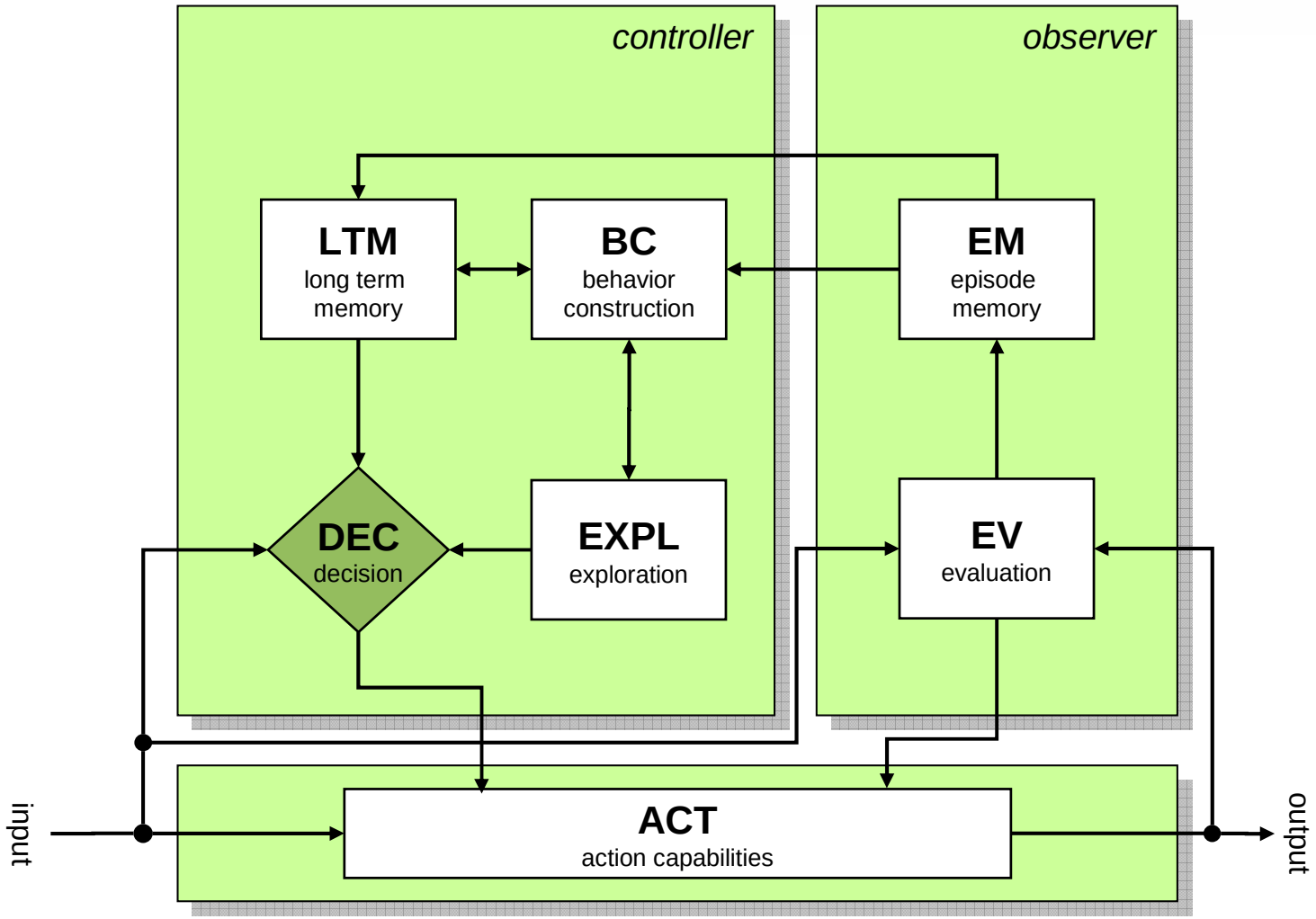


ESLAS within the SPP-OC

- **Our approach:**
  - Robot's individual adaptation guided by society's needs
    1. Selfish adaptation → sociologically based evaluation
    2. "Selfishness" dependent on the society's current needs
  - Robots having their own world model
  - |Society| << |Group| in typical ant algorithm applications

- **Related work within the SPP**
  - ***ORCA***
    Individual selfish adaptation without group aspect
  - ***SmartTeams***
    Strategies for exploration in groups without individual adaptation

Design and implementation of ESLAS

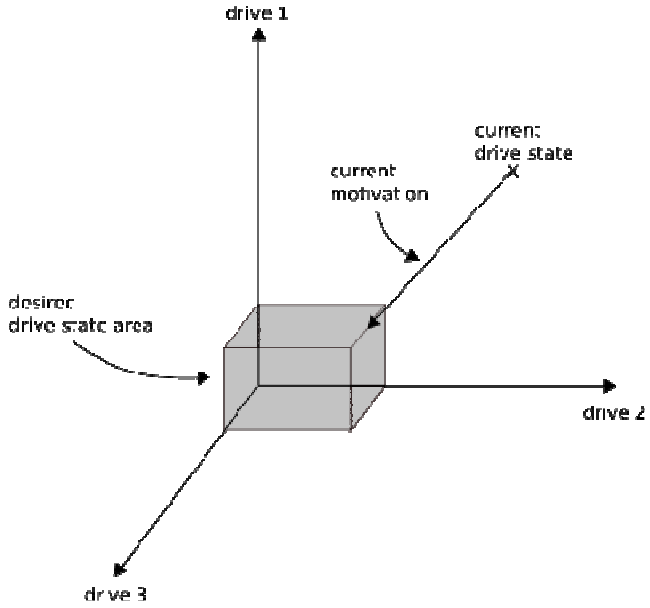


Evaluation system

- **Intrinsic high-level state of the robot**
  - Robot's goals defined by means of drives
  - Dependent on perception and time-dependent functions
  - Threshold defines state of "well-being" or satisfaction

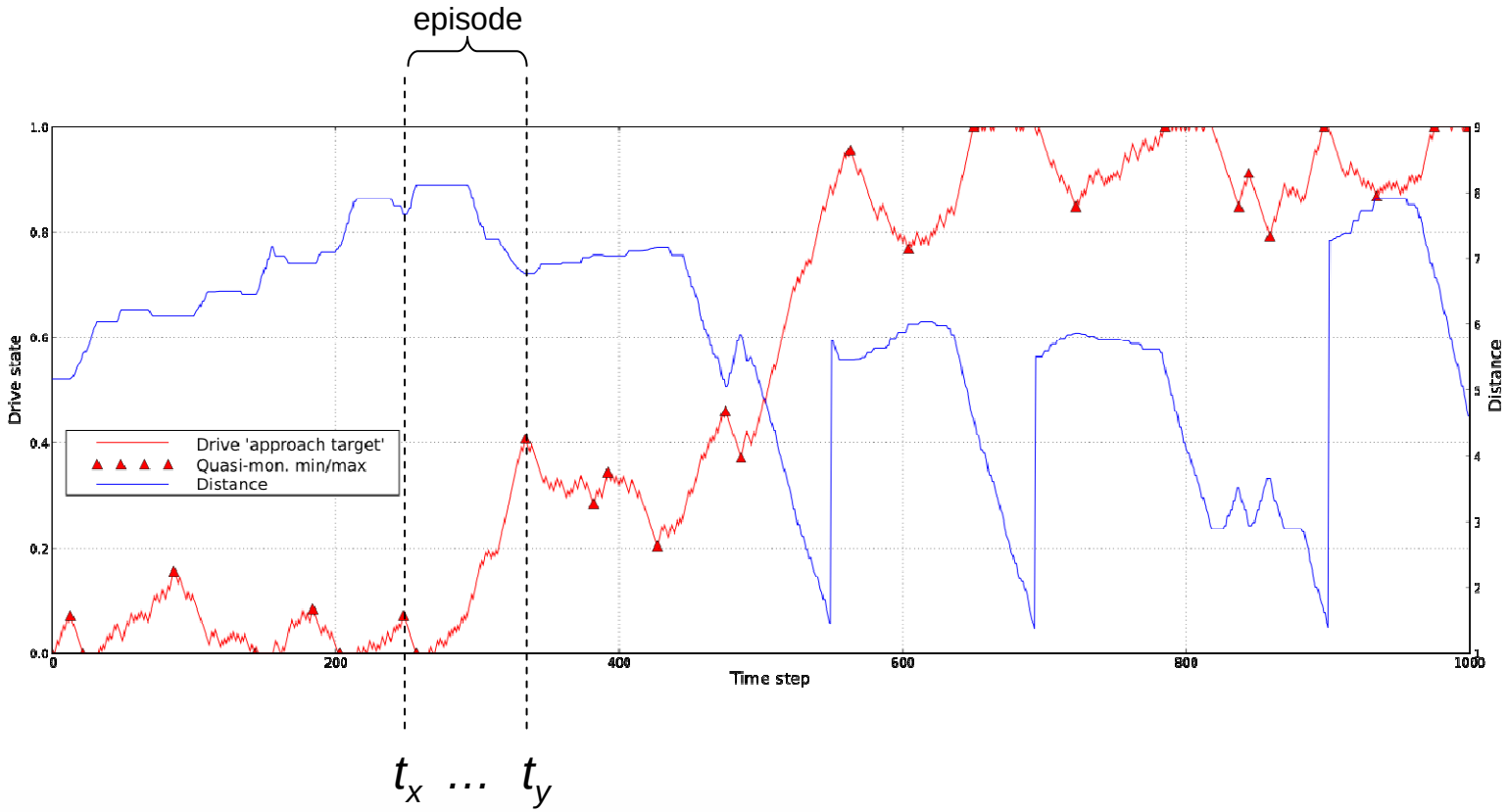
- **Drive examples**
  - Imitation
  - Task 1
  - Task 2
  - …

- **Generation of motivation**
  - Vector to "well-being region"
  - Dynamic drive state ⟶ dynamic motivation
    (useful e.g. for recurrent exploration)



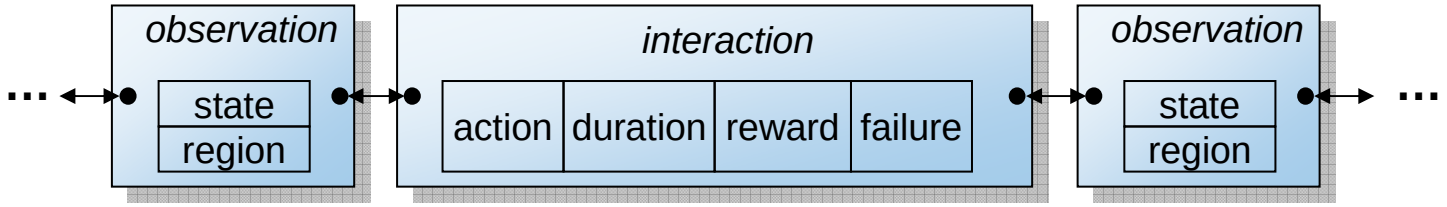
Episode Memory

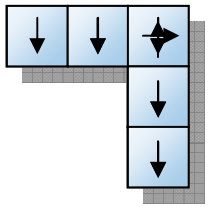
- Segmentation of the evaluation stream
- E.g. into quasi-monotonic intervals:

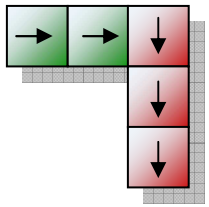


Individual learning: Strategies

The robot's stream of experience





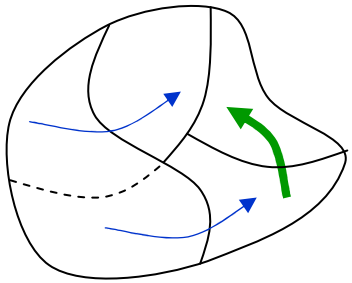


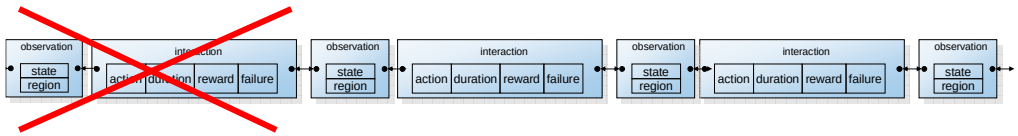
FailureRevisor

TransitionRevisor

SimplificationRevisor

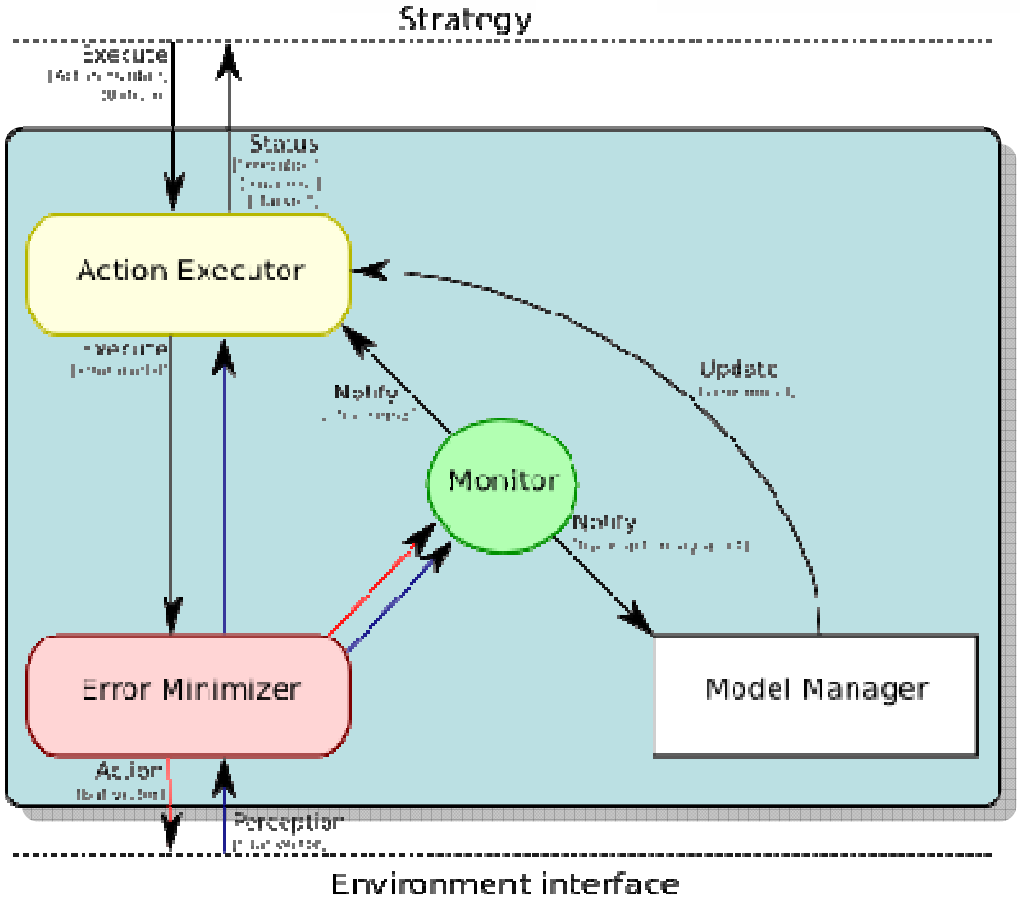
ExperienceRevisor



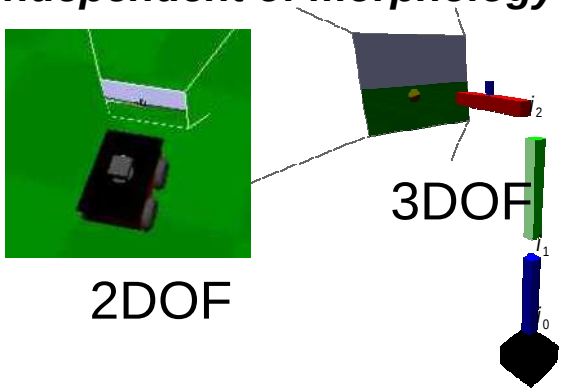


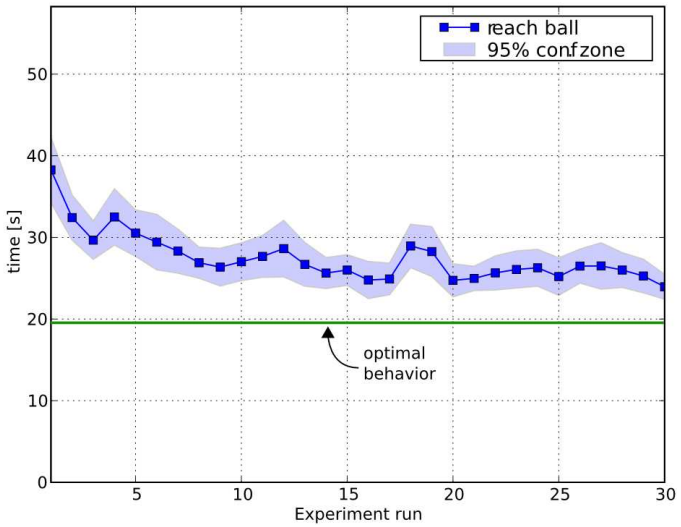
Inspired from [AMPS06]

Individual learning: Skills



Independent of morphology





Video example

Video showing on-line behavior creation with the Paderkicker

The challenges of imitation

1. Challenge

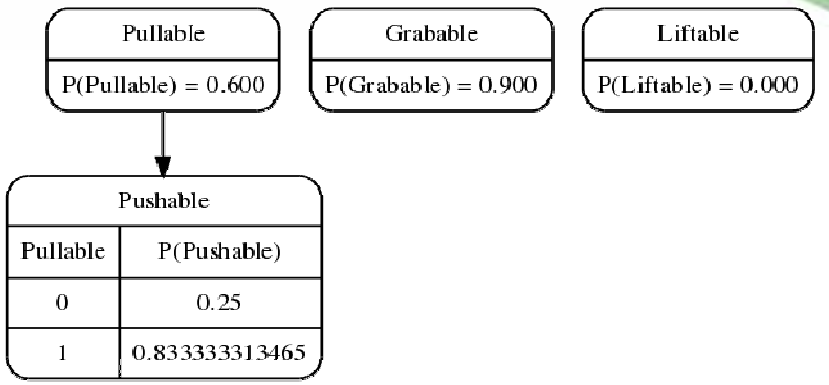
In a group of heterogeneous robots, whom should we imitate?

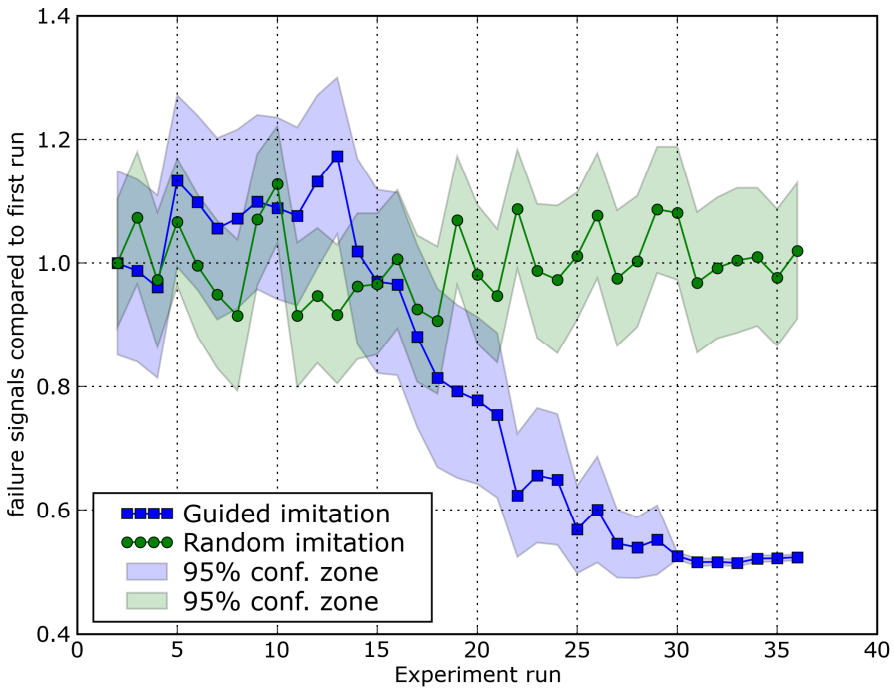
2. Challenge

When we have observed something possibly useful, how can we integrate that into our already learned behavior?

1. Challenge: Determining whom to imitate

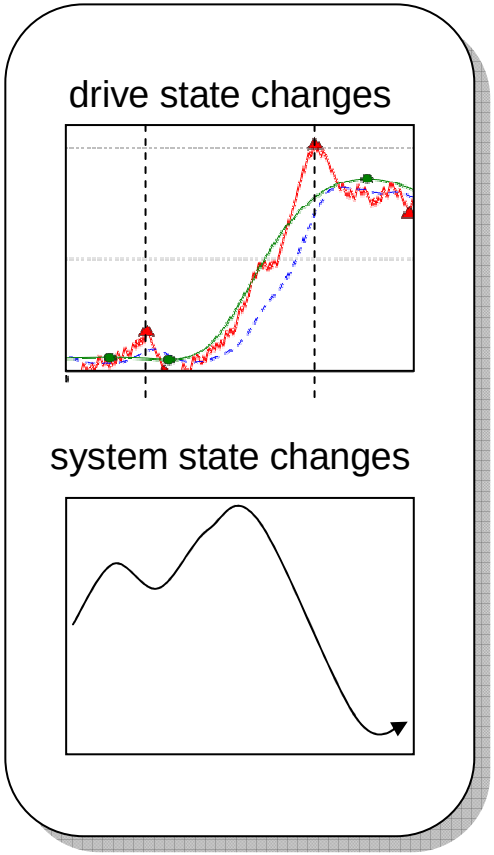
- **Solution**
  - **Affordance Networks** (AN) encoding other robots' capabilities as affordance dependencies via Bayesian Networks
  - **Modified Graph Edit Distance** to calculate similarity between the imitator's own AN and all the other visible robots' ANs
  - Choose the robot with the **highest similarity**



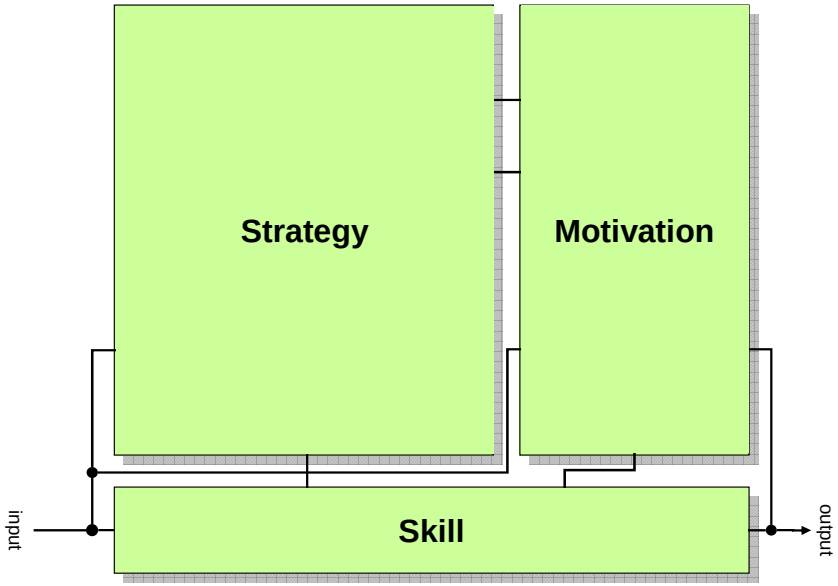


2. Challenge: Emergent behavior and imitation

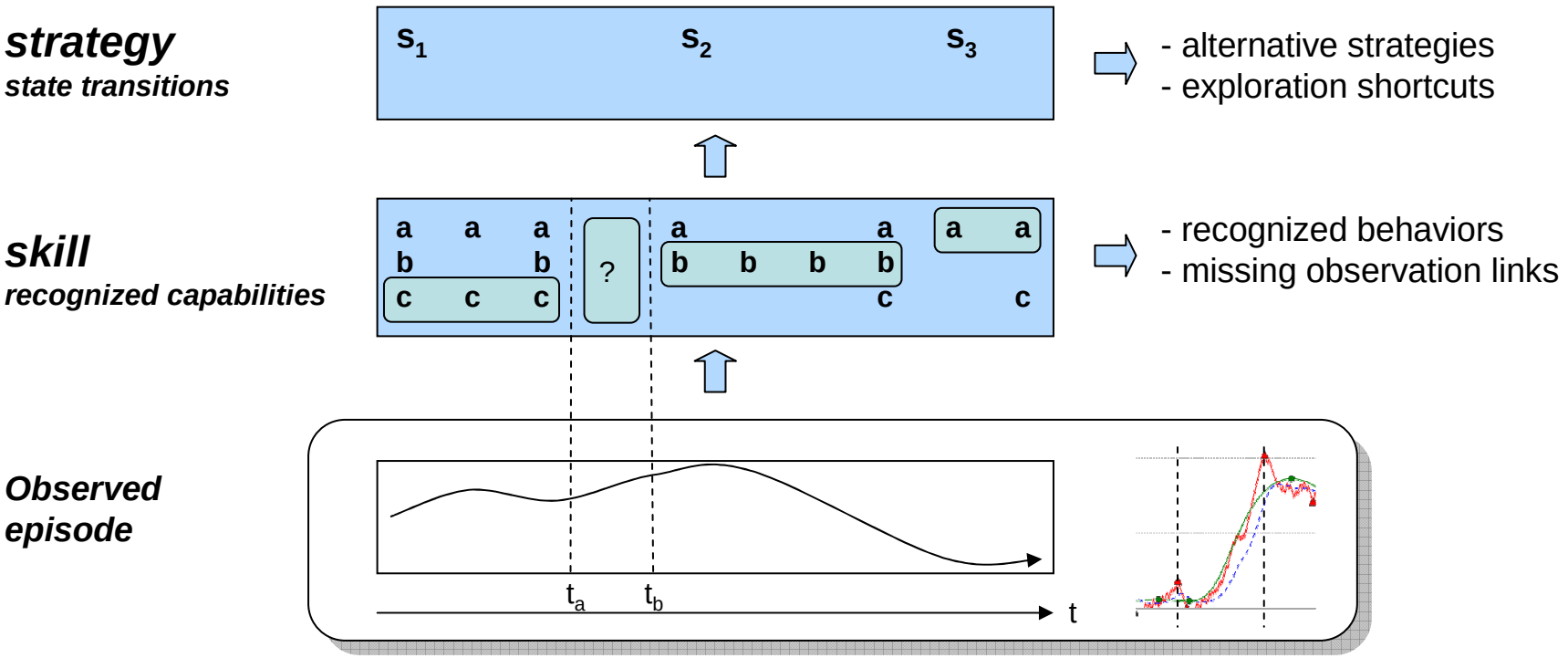
Observed episode



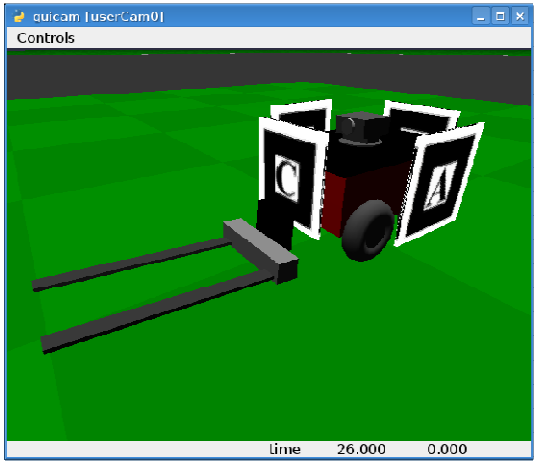
?

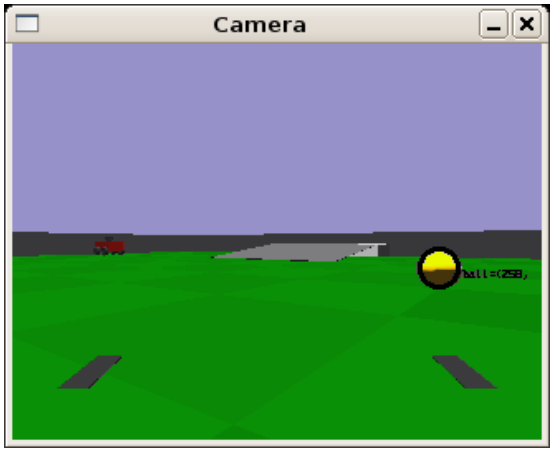


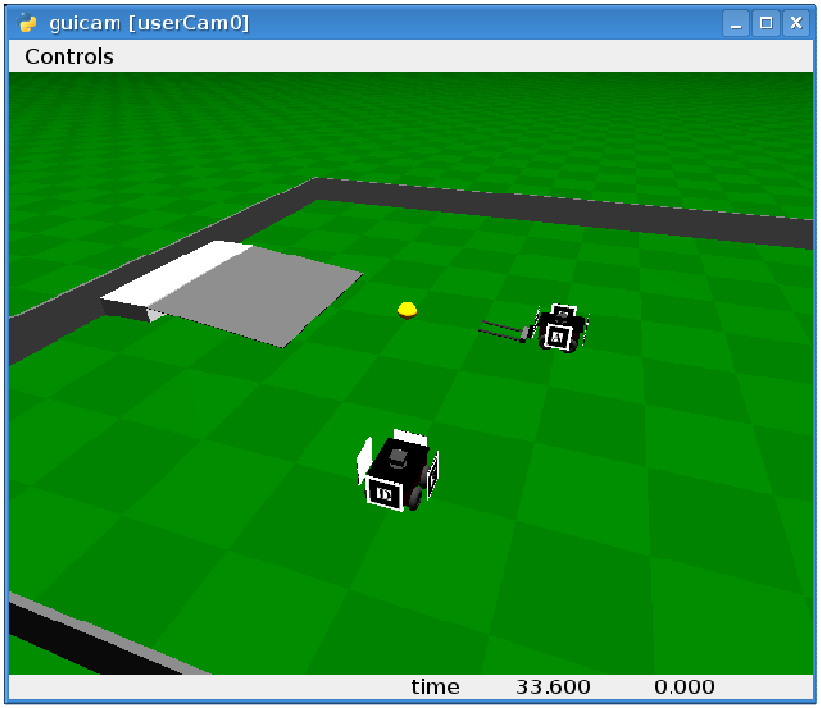
2. Challenge: Emergent behavior and imitation



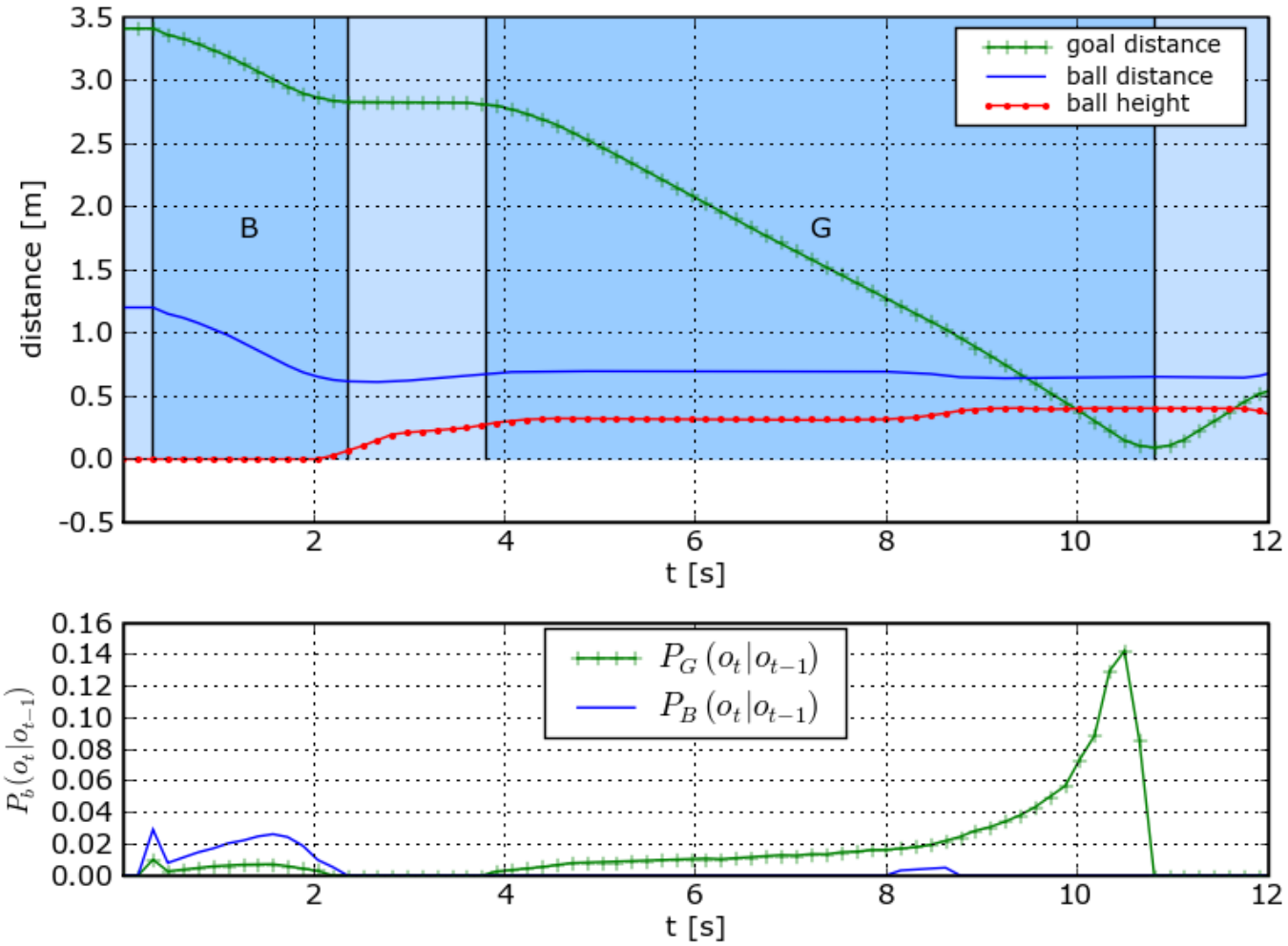
Imitation experiment setup



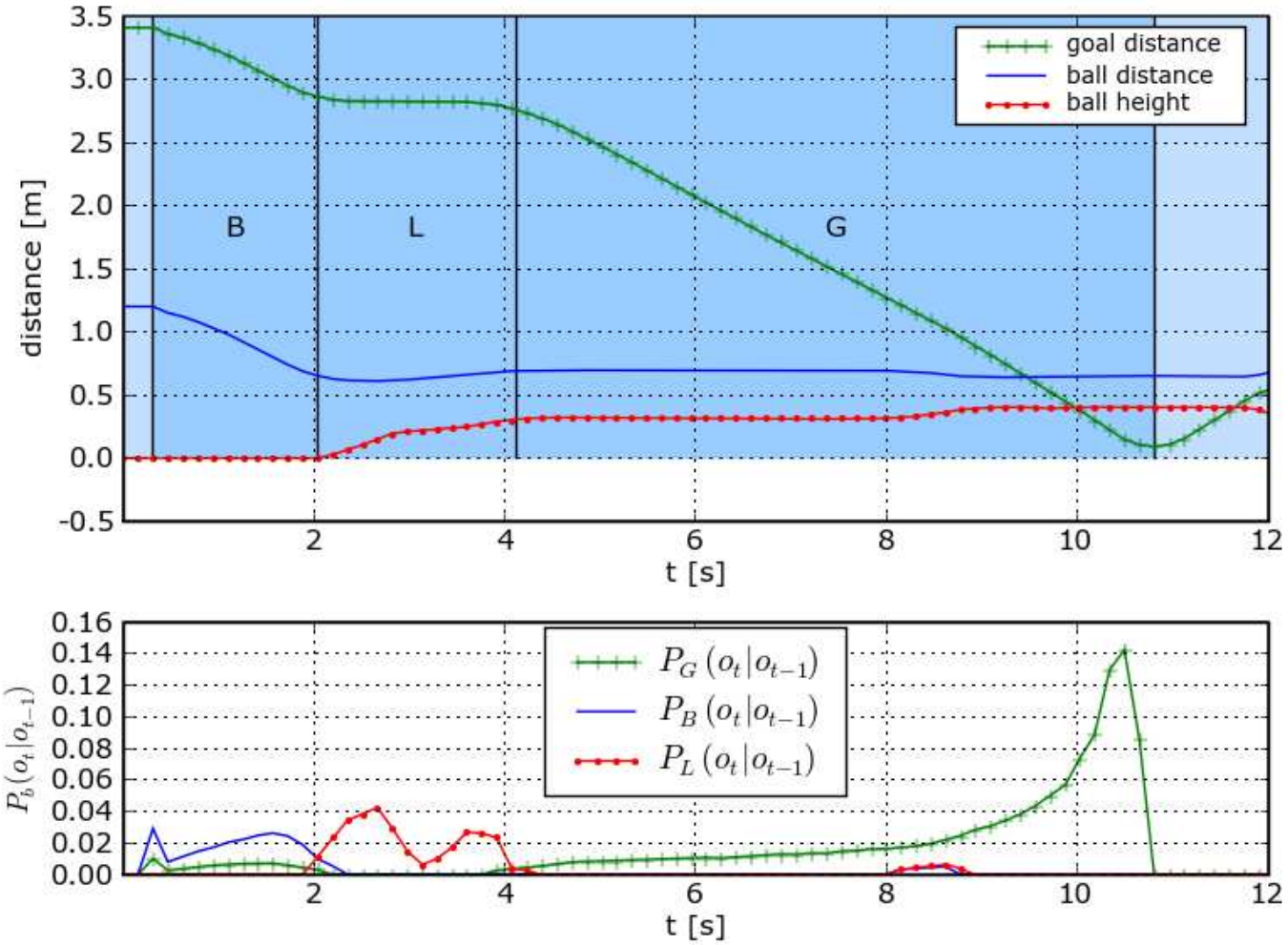




Experimental results (no lifting capabilities)

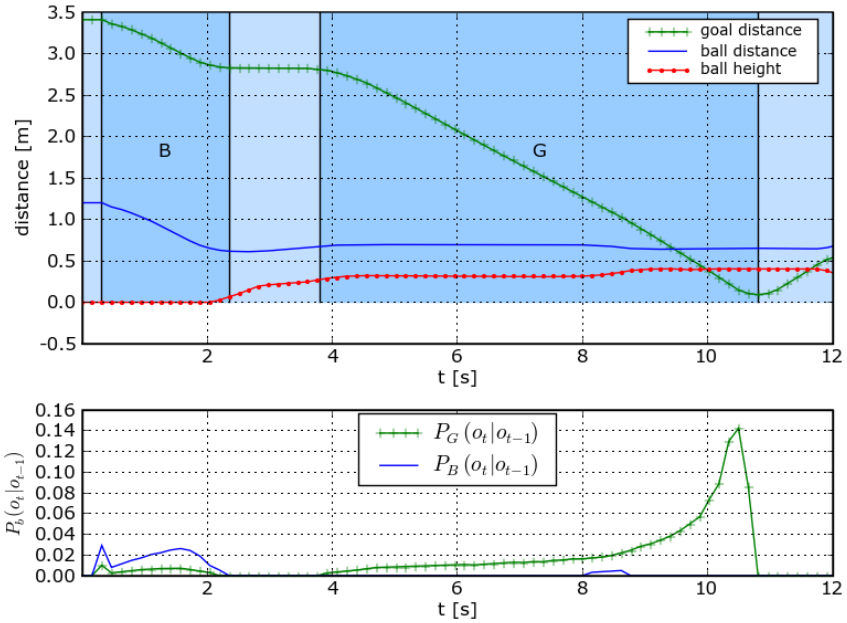


Experimental results (with lifting capabilities)



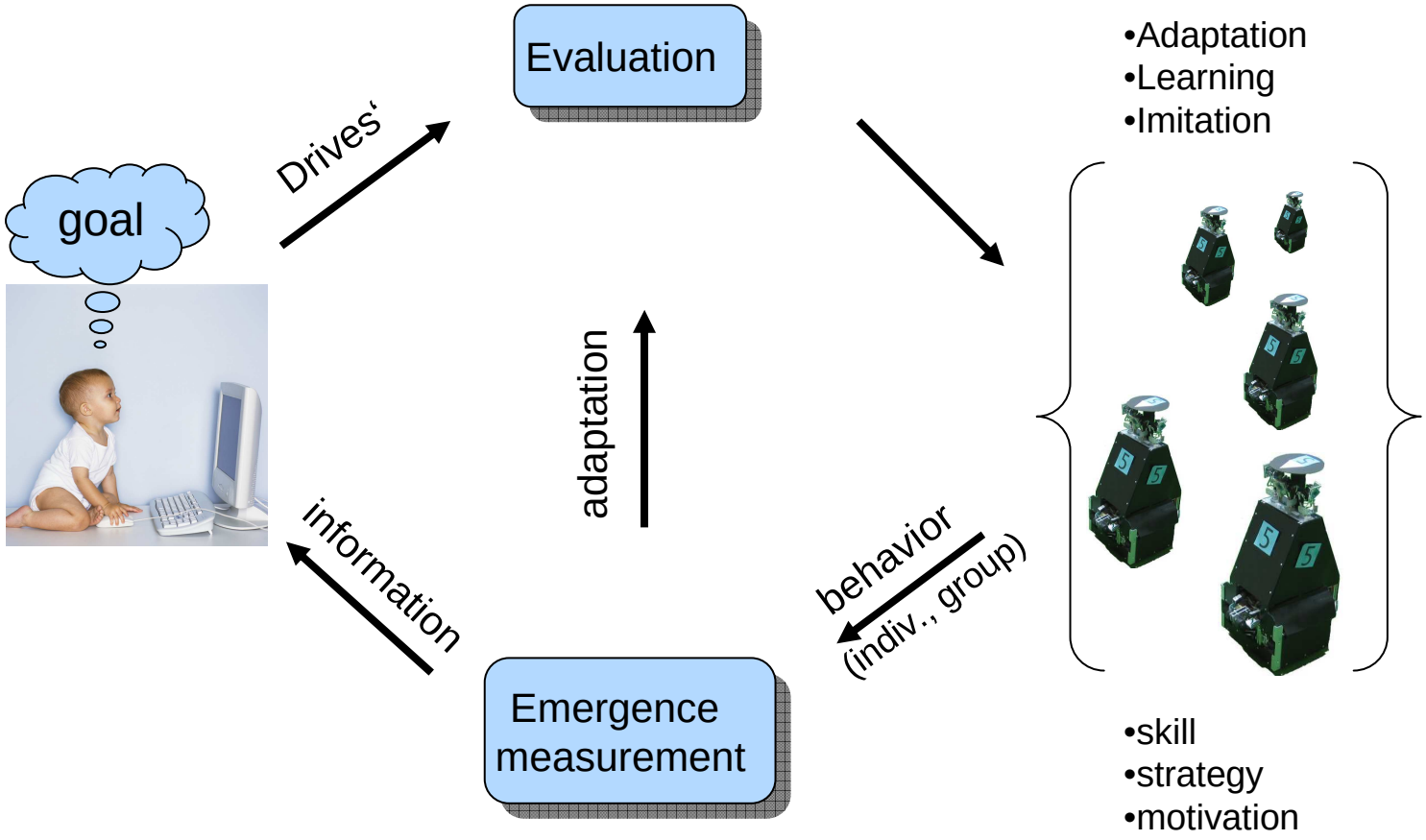
Exploiting (un-)recognized behavior

- Recognized sequences
  - Spend positive reward in own SMDP
  - Rethink greedy actions
- Not recognized intervals
  - Direct exploration efforts
  - Explore skills that bridge the unknown interval



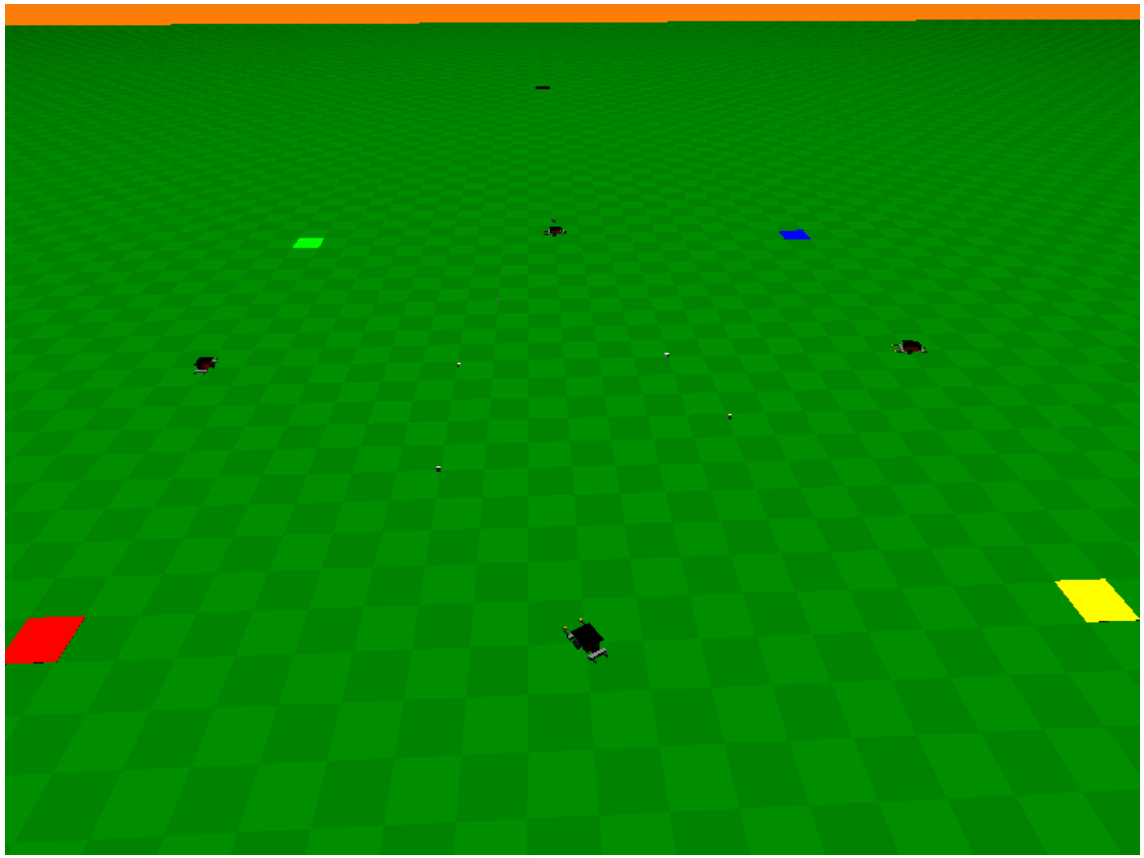
Emergence meas. and design methodology

- The vision of our design methodology:



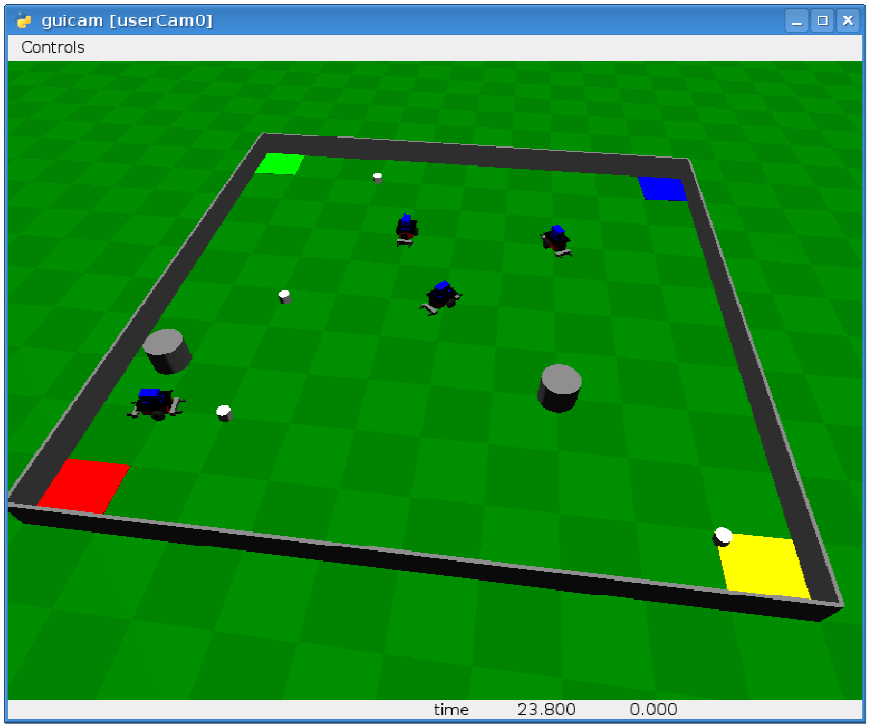
TODO in 2nd half of phase II

- Real-world imitation
- Up to now only “Division of Labor”-tasks are feasible with our framework

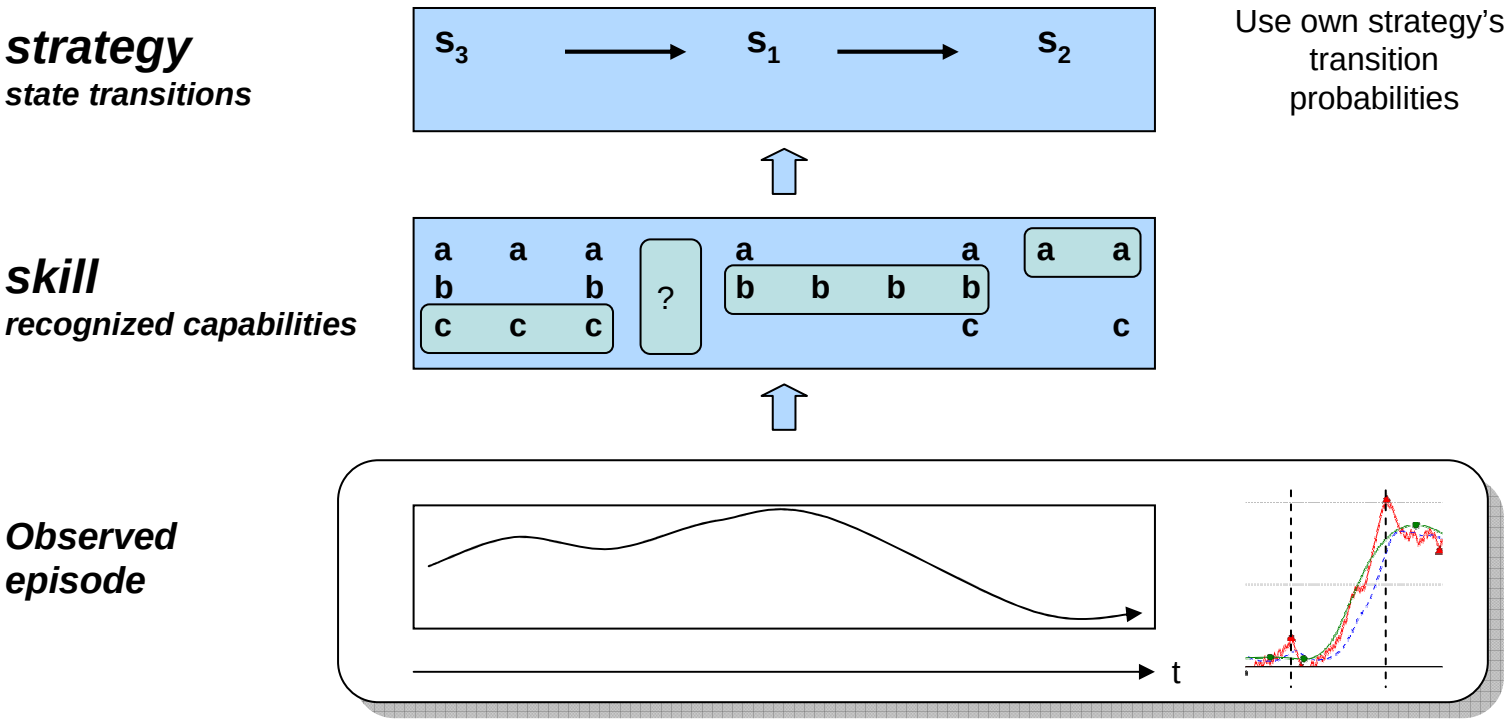


TODO in 2nd half of phase II

- Real-world imitation
- Up to now only “Division of Labor”-tasks are feasible with our framework
- Todo
  - Scenario, where cooperation is a necessity →
  - Use behavior recognition from imitation to perform teammate modeling (possible with minor algorithm changes)



TODO in 2nd half of phase II



Conclusion

- ESLAS – a modular approach for realizing self-organizing and self-optimizing autonomous systems
  - Emergent behavior in societies of such systems
  - Learning to adapt own capabilities to dynamic environments while paying attention to the overall group behavior
- Decentralized evaluation functions for assessing own behavior based on socio-biologically paradigms
- Learning combines individual adaptation with imitation to converge to desired group behavior

Outlook Phase III

- How to model teammate's behavior
  - Assumption "my teammate is similar to me"
    → Model deviations of expected behavior
  - Assumption "my teammate is quite different to me (knows nothing)"
    → Model the complete behavior
- Integrate some kind of "Theory of Mind" (Leslie/Baron-Cohen)
  - Speed up group's performance by integrating other's current goals
- Real-world experiments

Thank you for your attention!

Questions? Hints? Suggestions? Answers?

Publications (2007-2008)

- **Towards robust layered learning.** Willi Richert and Bernd Kleinjohann. In International Conference on Autonomic and Autonomous Systems (ICAS'07). IEEE Computer Society, June 2007.
- **A robust skill learning framework for autonomous mobile robots.** Willi Richert and Bernd Kleinjohann. In Proceedings of the 4th International Symposium on Autonomous Minirobots for Research and Edutainment (AMiRE'07), volume 216. 2007.
- **Increasing the autonomy of mobile robots by on-line learning simultaneously at different levels of abstraction.** Willi Richert, Olaf Lüke, Bastian Nordmeyer, and Bernd Kleinjohann. In International Conference on Autonomic and Autonomous Systems (ICAS'08). IEEE Computer Society, March 2008. Best Paper Award.
- **Guiding exploration by combining individual learning and imitation in societies of autonomous robots.** Willi Richert, Oliver Niehörster, and Florian Klompmaker. In IFIP Conference on Biologically Inspired Cooperative Computing (BICC'08). Milano, Italy, 2008.
- **Measurement of robot similarity to determine the best demonstrator for imitation in a group of heterogeneous robots.** Raphael Golombek, Willi Richert, Bernd Kleinjohann, and Philipp Adelt. In IFIP Conference on Biologically Inspired Cooperative Computing (BICC'08). Milano, Italy, 2008.
- **Hierarchically distributing embedded systems for improved autonomy.** Claudius Stern, Philipp Adelt, Willi Richert, and Bernd Kleinjohann. In Proceedings of the Working Conference on Distributed and Parallel Embedded Systems (DIPES'08), 2008.
- **Adaptivity at every layer – a modular approach for evolving societies of learning autonomous systems.** Willi Richert and Bernd Kleinjohann. In Proceedings of IEEE/ACM ICSE Workshop on Software Engineering for Adaptive and Self-Managing Systems (SEAMS'08). Leipzig, Germany, 2008.
- **Layered understanding for sporadic imitation in a multi-robot scenario.** Willi Richert, Oliver Niehörster, and Markus Koch. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'08). Nice, France, 2008.