GEFÖRDERT VOM
Bundesministerium
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CrESt Project Closing Event

Goal-based Strategy Exploration

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Problem Statement

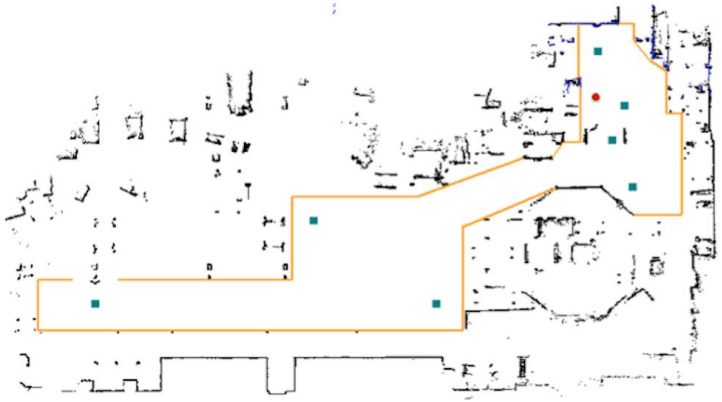
- In collaborative systems there are goals of the group as well as goals of individual participants
  - Example car platooning: group goal is to save fuel,
    individual goal is to reach a destination
  - Example transport robots: group goal is uninterrupted production,
    individual goal is minimal wear and tear
- Individual goals may support group goals, contradict them, or be orthogonal
- Quality of the system depends on the degree of goal satisfaction
- Research question: how can goals be used as a basis in the model-based development of collaborating embedded systems?
  - Formal description of goals and goal hierarchies
  - Avoidance of goal conflicts, definition of optimal behavior
  - Derivation of strategies and code from the description of goals
  - Evaluation of systems with respect to the defined goals

Use Case Transport Robots

- Driverless transport vehicles
  - Serving (loading and unloading) of production machines
  - Carrying loads of 20-200kg
  - Fleets of 5-20 robots
- Historical development
  - First generation: rails or following a line
  - Second generation: on dedicated roads
  - Third generation: moving freely with humans
- Vision for the future: serving of machines done by robots, humans only for supervision only
  - Presentation on marketplace EC3

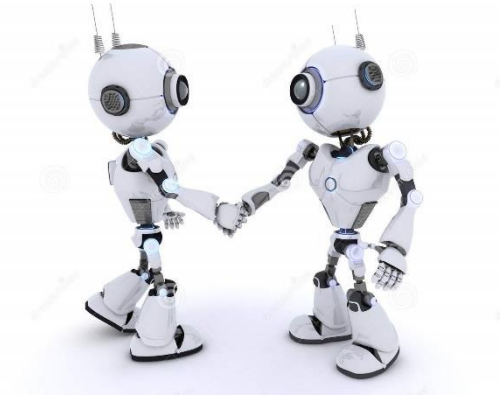
Use Case Challenges

- Localization and self localization
  - Laser scanner for safety and localization
  - Pre-mapping of factory environment
  - Maximum likelihood pattern matching
- Route planning
  - Dijkstra shortest path algorithm for overall route
  - Dynamic window algorithm for collision avoidance
- Job scheduling
  - Robot hardware may have failures, roads may be blocked etc.
  - Wireless communication may be distorted
  - Server as a single point of failure may break down



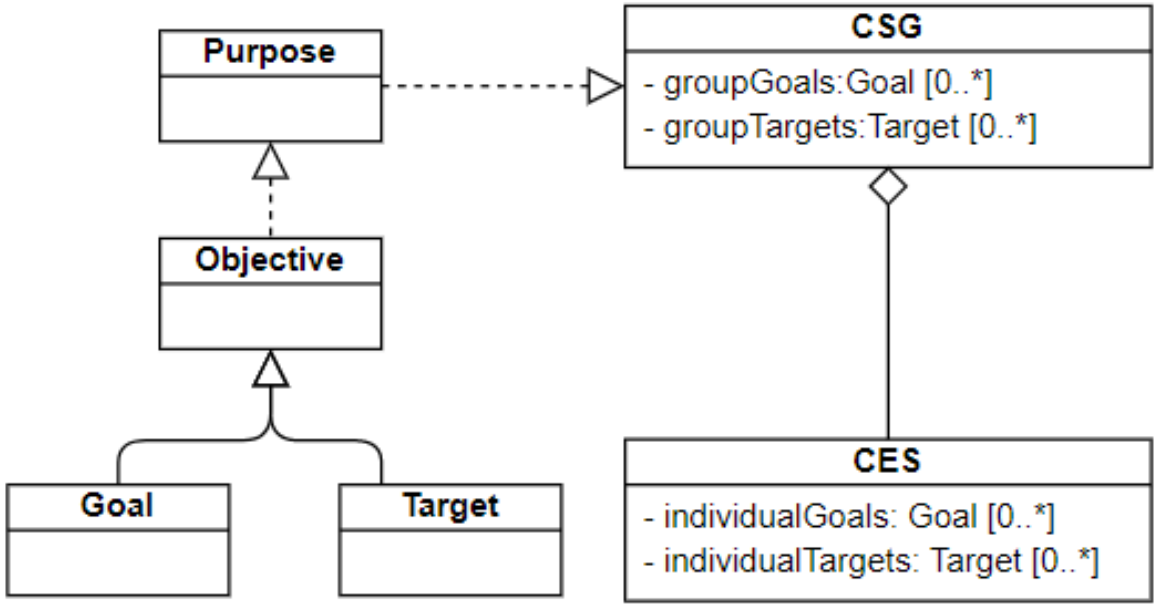
Collaborative Control of Transport Robots

- Challenges
  - Safety-critical (no collisions, no loss of tasks, no deadlocks, ...)
  - Open (new vehicles can join the fleet)
  - Inhomogeneous (not all vehicles completely alike)
- Auction-based coordination
  - Simple bidding: cost function
  - More complex approach: “virtual money”
  - Earn new money by completing a transport job
  - Spend money to buy a new job
- Advantages
  - More flexibility and robustness, higher throughput
  - Better scalability
  - More security



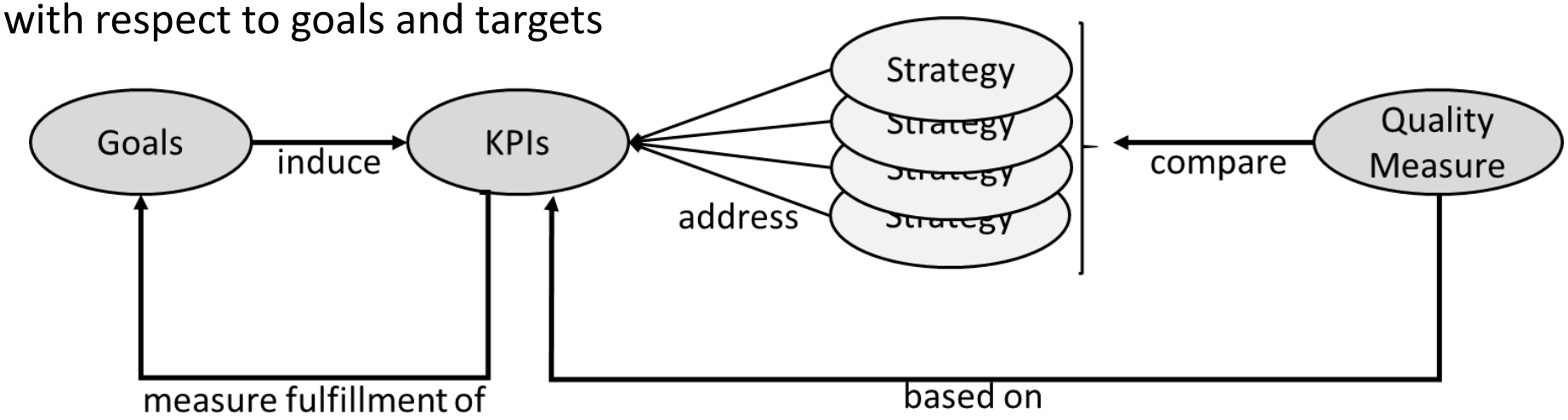
Solution (1)

- Distinguish between g*oals* (“hard goals”) and *targets* (“soft goals”)
- A goal is a set of states, a target is a fuzzy set of states
  - both describe what the system should accomplish at runtime
  - a goal shall be reached
  - a target shall be approximated



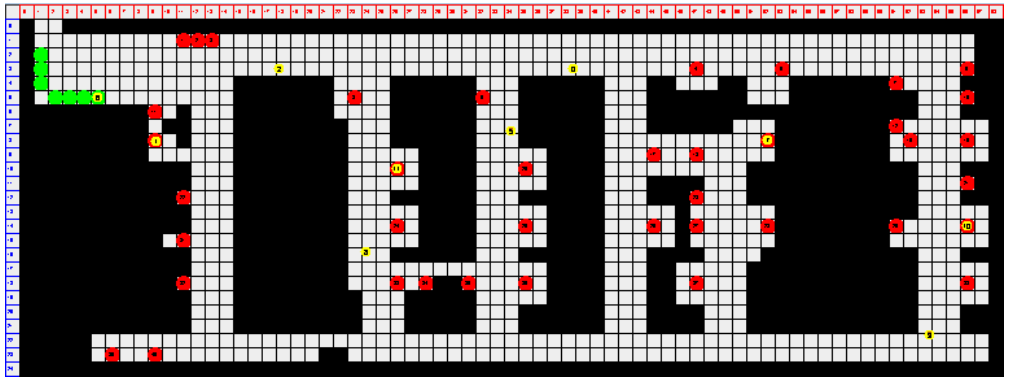
Solution (2)

- *Key performance indicators* (KPIs) describe the degree of goal fulfillment
- A s*trategy* is a function choosing one out of several possible actions, for a certain system and context state
  - The behavior of an autonomous agent is largely determined by its strategy
  - The overall system behavior of a group results from the behavior of its components
- A *quality measure* allows to compare different strategies with respect to goals and targets



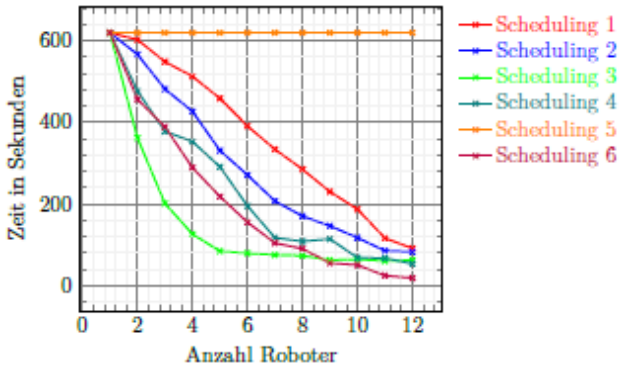
Solution (3)

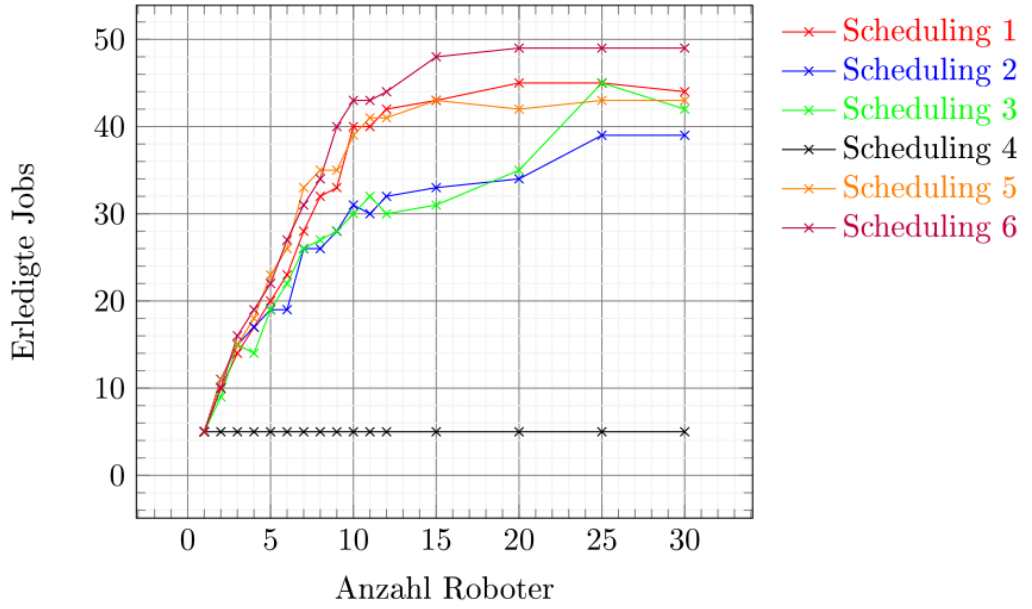
- Alternating Signal Temporal Logic (ASTL*) for the formalization of KPIs
  - $\mathbf{G}(Batt.lvl \geq 0.4 \wedge Batt.lvl \leq 0.7)$
  - $\langle\langle bid.i.j \rangle\rangle \mathbf{G} \forall k(waitingtime(m_k) \leq 100)$
- Robust semantics reflect the quality measure
- Discrete modelling of scenarios and actions
  - e.g., floor plan, robots, docking stations
  - Auction system for job scheduling
- Using model checkers to generate strategies
- Using simulators to evaluate strategies



Results (1)

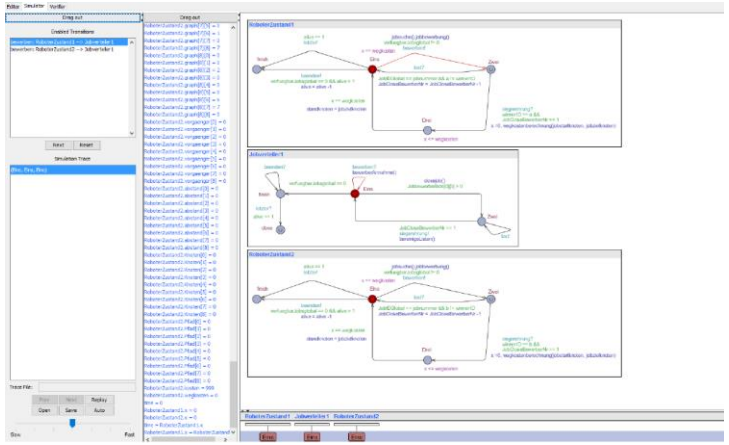
- Simulative evaluation of goal-based strategy development
  - Definition of a quality measure for strategies regarding, e.g., equal wear of tear of robots
  - Simulative comparison of several strategies for transport robots (first-come-first-served, shortest-path, shortest-time, lowest-workload, best-energy, …)
  - Strategy defined after formal definition of quality measure improved goal fulfillment by nearly 20%





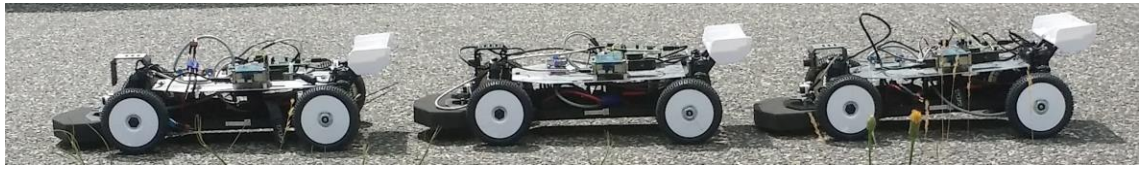
Results (2)

- Different kinds of properties were analyzed
  - Temporal properties, e.g., no deadlocks, safety and liveness, …
  - Timing properties, e.g., responsiveness, best/worst timing, …
  - Performance properties, e.g., throughput, utilization rate, …
  - Fault tolerance properties, e.g., roadblocks, failures, …
  - Flexibility properties, e.g., additional robots and stations, alternative floor plans, …
  - Strategic properties, e.g. security, intruders, traitors, goals & strategies, …
- Model checking approach is subject to state explosion problem
  - Combination with abstraction refinement techniques
  - Combination with machine learning approaches



Success stories

- Car platooning: „Velox“ model cars
  - Educational component
  - Integrating machine learning; safety?
- Transport robot use case
  - First decentralized industrial solution
  - Specification and validation of adaptive goals
  - (Decentralized) monitoring
- New industrial project „Commissioning of parts“
  - Collecting items from a storage
  - Storage goes to commissioner (not vice versa)



DLR Projektträger

Collaborative Embedded Systems

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Fragen ?